



Activities and Policies to Enhance Forest and Agricultural Carbon Sinks in California

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Executive Summary

- California forests are currently a sink, offsetting over 4% of state emissions.
- California forests and soils are a large reservoir of carbon, and avoiding loss of this carbon avoids emissions thirty times the total annual state emissions.
- Sequestration is increasing the carbon stock of forests or soils, averaged across the landscape.
- Afforestation may provide 3.5 million metric tons CO₂e per year of sequestration, for at least 80 years. If land purchase or rental is not required the cost could be as low as \$6 per ton CO₂e. Cost per ton rises as the land cost rises, reaching \$70 per ton when land costs are \$5,000 per acre.
- Thinning to promote forest health and using the thinned material to displace fossil fuel may provide 3.7 million metric tons CO₂e, indefinitely, for a price of \$10 per metric ton CO₂e or less.
- In terms of tons, the greatest potential comes from thinning to promote forest growth and burying the wood removed from forests, sequestering 9.5 million metric tons CO₂e per year. This strategy forgoes other values that could be gained from harvested wood and is expected to cost \$24 to \$96 per metric ton CO₂e.
- Other strategies that could sequester carbon in lands include switching from plowing to no-till cropping, converting hardwood stands to conifer, extending forest harvest rotations, reducing clearing of forest lands, and encouraging homeowners to grow larger yard trees.
- Afforestation, converting hardwood stands to conifer, and extending timber harvest rotations will provide little or no benefit for the first 10-20 years after initiation of the activity but can provide substantial benefits over several decades. Thinning, reducing clearing, switching to no-till, and enhancing hard trees can provide benefits more quickly.
- Carbon sequestration can be achieved by (a) allowing landowners to opt into a system that controls industrial emissions and sell offsets to industrial emitters, (b) public purchase of offsets via auction, or (c) establishing a requirement that large landowners maintain specified amounts of carbon within their lands and allowing them to sell offsets based on gains of carbon above any required amount. Some types of sequestration or emission reduction could be achieved by requiring use of specific land management practices.
- Who pays and who benefits varies depending on the policy approach. Emitters and their customers pay under cap and trade systems, taxpayers pay for public purchases of offsets, and landowners pay when specific practices are required.
- Offset and cap-and-trade systems can achieve a given degree of benefit for less overall cost than regulatory systems that require use of specified practices or technologies.
- A cap and trade system for forest lands that includes private landowners who own 1,000 acres or more would encompass nearly 40% of private forest lands and include about 1,000 landowners.

Background

Climate warming is occurring and is disrupting ecosystems on which people depend. A substantial portion of current climate change results from increasing amounts of greenhouse gases in the atmosphere trapping more heat. Most of the increases in atmospheric greenhouse gases are effects of human activities. The gas causing the largest increase in warming is carbon dioxide (CO₂) from burning of fossil fuels such as coal in power plants and gasoline in cars. CO₂ also comes from clearing of forests and tillage of agricultural soils. Clearing forests and tilling soil causes carbon in vegetation biomass and soil organic matter to be converted to CO₂ and emitted to the atmosphere.

Avoiding disruptive climate change will require substantially reducing global net emissions of greenhouse gases. Substantial emissions reductions cannot be achieved without reducing emissions from fossil fuels. However, part of the solution can be maintaining and restoring stocks of carbon in forests and soils.

This paper summarizes analysis of options to maintain and increase amounts of carbon stored in California forests and soils, estimates costs, and discusses policy options for achieving these land management outcomes.

Recent California Forest Carbon Stocks and Flows

Gross California greenhouse gas emissions in 1999 were estimated to be 427.72 million metric tons CO₂ equivalent (MMTCO₂e)¹ per year. Carbon sinks into forests and soils were estimated to be a net increase of 9.5 MMTCO₂e in 1999, plus an additional increase in net sequestration in wood products and landfilled yard trimmings of 9.3 MMTCO₂e that year (Public Interest Energy Research 2002). At these rates, forest growth and movement of carbon into wood products offset about 4.4% of gross state emissions. A later estimate put net forest and soil sinks at 7.55 MMTCO₂e per year (Brown et al. 2004b).

Avoiding emission of the carbon stored in forests may have a greater effect on net state emissions than the approximately 8 MMTCO₂e per year sink. In 1997, forests occupied 39.7 million acres in California, which is 39.8% of the 99.7 million acres within the state. The total carbon stock in forests, including trees, shrubs, woody debris, the forest floor and soil, was estimated to be 12,600 MMTCO₂e in 1997 (Birdsey and Lewis 2003). This estimate of the total carbon stock in forests and forest soils (not counting agricultural soils) is more than 30 times the total net annual state emissions in 1999. Because forest and soil carbon stocks are large, a small percentage change in these state-wide stocks can have a significant effect on total net state emissions, either sequestration that would

¹ A note on units: Carbon dioxide equivalent units are used to compare the warming effects of different gases that have different warming effects per ton of gas in the atmosphere and different lifespans in the atmosphere. When one ton of carbon is converted to carbon dioxide, 3.667 tons of carbon dioxide are produced. All tons are metric tons unless otherwise stated. One metric ton is 2204.6 pounds. State wide totals are given in millions of tons CO₂e; project numbers are given in tons CO₂e.

mitigate other emissions, or emissions from lands that could significantly increase total net state emissions.

California Forest Carbon Accounting Protocols

The California Climate Action Registry has established protocols for reporting sequestration resulting from changes in carbon stocks on forest ownerships and reporting results of projects to sequester carbon in forests.² This protocol describes a method for quantifying change in forest carbon stocks over time, and the protocol has been agreed to by the California Department of Forestry and some groups active in forest policy development in the state. This protocol could be used as the basis for developing an accounting system for a cap-and-trade or offset system for forest carbon stocks.

The protocol allows landowners to count carbon stored in forest products, which may be acceptable for state-level policy actions to mitigate emissions. However, forest landowners would have difficulty showing ownership of offsets based on carbon physically located in wood products owned by others. In a market system for offsets, allowing landowners to claim this indirect benefit could lead to double counting of sequestration. Also, the methods do not count emissions from “natural” disturbances, which can lead to accounts failing to reflect actual emissions. The protocols do have the advantage over some other methodologies in that the default method for determining the baseline for projects that avoid deforestation is to observe the rate of land conversion occurring in the county where the project is located. This method is more objective than methods that rely on barrier analysis. The protocols do not contain methods for accounting for displacement of production of goods by projects. This displacement is called leakage and methods for calculating this type of displacement are given in Murray et al. (2004).

² www.climamaterregistry.org

Concepts in Carbon Sequestration

Several factors must be understood to evaluate the feasibility and desirability of options to mitigate greenhouse gas emissions by sequestering carbon in lands. Selected key concepts are discussed here.

Different Perspectives Lead to Different Valuations

Depending on one's perspective, different aspects of carbon sequestration activities take on different degrees of importance. When considering greenhouse gas benefits that could be generated by changing land management, it is important to consider proposed policies from both a broad public policy perspective and from the perspective of actors who would implement individual projects.

Broad public policy issues include non-market benefits, such as water quality and wildlife habitats. Policy makers also consider whether a policy transfers wealth from one group to another, and if so, whether this transfer is desirable. Specifically, policy makers should consider which citizens or firms bear the costs of new policies, and who receives benefits. Social considerations are an aspect of public policy judgments, including whether a proposed policy enhances or limits opportunities of citizens, and whether it enhances or hinders citizen efforts to earn a livelihood.

Both public and private decision makers seek to mitigate risk. Public decision makers should also consider whether a proposed policy increases or decreases the risk of catastrophes (such as large numbers of homes being burned by wildfire), and whether policies will increase the demand for limited public funds (such as funds for fighting wildfires). Private firms focus on risks that they will not be able to earn expected revenues, or that costs will be higher than expected. Some leading firms are now assessing costs likely to result from climate change, and some firms have concluded that the costs of reducing emissions and avoiding climate change are less than their costs of adapting to climate change.

Another perspective is at the scale of individual projects, evaluating how much greenhouse benefit an individual project or class of projects can provide, and for what cost. Both public policy makers and private project developers seek greater benefits and lower costs.

Stock Versus Flow

The carbon stock of a forest is the amount of carbon present within a specified area at a specified point in time. A rate of emission or sequestration is a quantification of flow. For example, a project that grows trees might add carbon to a site, during a specified period, at a rate of five tons CO₂e per acre per year, and this rate is the net flow.

An increase in carbon stock is sequestration. In forest and soil carbon sequestration projects, the goal is to increase the terrestrial carbon stock over time, and hold the stock—on average—at a new, higher level. Calculations of quantities of carbon stocks may be averaged over heterogeneous areas, and specific points within the area might have stocks or stock changes quite different from the average. For example, a forest landowner that is increasing its average forest carbon stock per acre across its entire ownership, by growing trees larger, may still have individual acres that are harvested. The harvested areas within the ownership would lose carbon during the accounting period when the harvest occurs, even if the ownership as a whole is gaining carbon. Similarly, a forest land owner might reserve one acre and let it grow and increase its carbon stock, while simultaneously decreasing timber and carbon stocks on the rest of the ownership, causing an aggregate reduction in the carbon stock present on the ownership.

When determining the net greenhouse effect of a forest project, one must consider what happens to the overall carbon stock, not just the rates of sequestration at different times. In particular, forest stands approaching maturity can gain carbon at relatively high rates. Old forests gain carbon at relatively slower rates but can hold very large carbon stocks. Converting an old forest to a young forest can increase the rate of sequestration, but only at the expense of a large net emission from the loss of much of the carbon stock held by the old forest, resulting in a substantial net increase in greenhouse gases.

Sequestration can count as an emission offset if it is beyond baseline amounts of sequestration, quantified, verified, owned by the seller, and not cancelled by displacement of emissions to other locations. During an accounting period, new sequestration can create new offsets. Continuing to hold tons of carbon stored in prior accounting periods maintains this prior sequestration (and maintains offsets based on this sequestration) and does not create new sequestration or new offsets. New offsets require a new net flow of carbon into the project area (assuming a non-declining baseline).

Knowing the rate of net carbon flow of a project is important because the flow rate determines how quickly a project can deliver offsets. In biological sequestration projects, net carbon flow rates generally are not constant over time. Net carbon flows vary with several factors including the time since disturbance, the developmental stage of trees, carbon stock, weather, and other factors. Some types of forest sequestration projects, such as afforestation and thinning project, have little or no sequestration during the first few years after the project is started.

Levelized Cost

Anyone—whether a public policy maker or private project developer—considering devoting resources to reducing greenhouse gas emissions should be concerned about the cost per ton of emission mitigation. When mitigating greenhouse gas emissions by changing land management, costs and benefits often occur at different times. Levelizing costs is a method of quantifying the effects of time on the cost of benefits of an activity.

To understand the fundamental issue of time, consider this question: If someone is going to give you \$1,000, would you rather have it right now, or in ten years? Pretty much everyone would prefer to have it now. If you are going to mitigate a hundred million tons of greenhouse gas emissions, would you rather have this mitigation today, or in 50 years? Thinking about it, everybody would rather have the environmental benefit sooner rather than later, all other things being equal. In the case of climate, failing to mitigate emissions in the next few decades could lead to irreversible climate change, and later mitigation of emissions after the climate changes might have little value.

Discounting is the method for quantifying how strongly people would rather have something sooner instead of later. Discounting is also used in finding the present value of future costs and benefits. Discounting applies to benefits as well as costs, because we prefer to have environmental benefits (or mitigation of environmental harms) sooner rather than later.

In many land use and forest projects, the costs and benefits occur at different times. For example for afforestation project, most of the costs occur in the few first years of the project, but most of the sequestration benefits do not occur for decades. Projects with different streams of costs and benefits can be compared by levelizing the costs per unit of benefit. Levelizing the cost of greenhouse gas emission offsets is done by discounting both the streams of costs and benefits, and dividing the discounted cost by the discounted number of tons:

$$LevelizedCost = \frac{\sum_{t=0}^T Cost_t / ((1 + d)^t)}{\sum_{t=0}^T Tons_t / ((1 + d)^t)}$$

Where $Cost_t$ and $Tons_t$ are the undiscounted amounts that occur in each period t , from period 0 to period T , and d is the periodic discount rate.

Levelizing requires choosing a discount rate. Typically, discount rates are given on an annual basis. When discounting costs, the discount rate is typically considered to be the opportunity cost of doing something else with the money, as indicated by interest rates on low-risk loans that actually exist (after subtracting out inflation and the transaction costs of issuing the loans). Often the interest rate on a relatively short term government bond is used to indicate the actual discount rate in practice. When analyzing alternative investments of public resources, most studies use a discount rate somewhere in the range of 3% to 5% per year, and many studies use 4%.

There is often discussion of what discount rate should be used for discounting future environmental benefits. Some people argue that a discount rate of zero should be used, to properly value preservation of our natural heritage for our children. However, this logic is not correct. In theory, the discount rate for environmental benefits would be the marginal rate of social benefit from achieving one more unit of environmental benefit. In

the case of avoiding the harm of climate change, the value of mitigating emissions would be the avoided loss of welfare that would occur as a result of climate change that would occur without the mitigation. In practice, we generally do not know the marginal rate of social benefit of environmental goods, or the marginal welfare benefit of avoiding harm.

Because we do not know marginal environmental damage curves, we must find an indicator of social preferences over time. Government investments in projects to improve social welfare provide such an indication. If government, as the primary agent for executing collective social goals, invests in some project, the money invested is taken from current consumption. To justify the investment, the return on the project must be equal or greater than the value of the consumption forgone by members of society, plus compensation for waiting.³ Because society has limited resources, it is not possible to execute all possible projects that yield social benefits. If a government does one project, it forgoes some other projects. If a government is going to execute more projects than it has cash to fund, to some degree it can borrow money and do more projects now. But even governments cannot borrow infinitely large amounts of money. By choosing to implement a project, public decision makers indicate that the value of that project is at least the value of current consumption, or is worth at least the cost of repaying the money borrowed to fund the project. And the time value of this spending is the rate of interest a government pays on bonds it uses to borrow money to fund public projects. These bond interest rates paid by reliable and solvent governments are the most widely accepted indicator of actual discount rates for costs. As a result, the appropriate discount rate for social benefits is the same discount rate used for social costs.⁴

Assigning Costs to Multiple Outputs

Forests provide many benefits, including marketed products such as timber, and outputs that are not generally marketed, such as clean, moderated flows of water and habitat for wildlife and fish. However, the cost analyses in this report assign all costs to greenhouse gas mitigation.

In practice, forest managers and citizens receive multiple benefits from forests and soils, and the practice changes analyzed here would provide multiple benefits. Costs should be considered as contributing to all the benefits yielded by lands, not just greenhouse gas emission mitigation. Policy makers or land owners may wish to allocate some costs to other benefits, reducing the price that would have to be paid to get an incremental increase in carbon benefits.

³ Even if a society values future consumption the same as consumption today, if productivity is increasing over time and additional consumption has declining marginal value, then society would prefer consumption now to consumption later, because productivity increases will make future marginal increments of consumption of lower value than a marginal increment of consumption today.

⁴ For a more formal—but still relatively comprehensible—presentation of this argument, and a review of the related literature, see Boscolo et al. (1998).

When considering costs, the revenue that is foregone by implementing a greenhouse emission mitigation project should be considered as a cost. If the management change that increases greenhouse gas emission mitigation eliminates some other benefit, then the value of that lost benefit should be considered to be part of the cost of achieving the greenhouse benefit. Specifically, if wood is removed from markets for timber and wood fiber—such as would be the case if merchantable material removed during thinning operations is buried in a landfill—then foregone revenue from wood products must be counted as part of the cost of the greenhouse benefit of sequestering wood in a landfill.

Baselines

Emission mitigation is what is accomplished beyond a baseline amount. In a regulated cap and trade system, the baseline is assigned. Outside of regulated systems, the baseline is the net emissions and sequestration that likely would have happened if the project did not occur.

Baseline carbon stocks and emissions can be constant over time, can rise over time, or can fall over time. An example of a baseline that is constant over time would be a forest ownership where the forest is fully regulated, and growth exactly equals harvest, and decomposition of woody debris exactly equals mortality that is not salvaged. An example of a baseline that is rising over time would be a riparian area that had been de-vegetated by years of heavy grazing, and where rules have recently changed that limit riparian grazing, and vegetation is now recovering, growing, and sequestering carbon. An example of a baseline carbon stock that declines over time would be a forest in a region where developers are clearing forest land and emitting stored carbon. A project could take action to serve the demand for cleared land with a smaller area of clearing. For example, a project could increase the number of dwelling units per acre cleared, providing new houses at the same rate but with less new clearing. The reduction in the rate of emission from clearing could provide an emission benefit even if the carbon stock on the unconverted lands remains constant. A project may cause a reduction in the rate of emission, even if the terrestrial carbon stock is declining. However, the carbon stock declines of the project must be less than the carbon stock declines without the project, and the baseline should be constructed very conservatively.

Of course, it is logically impossible to know what did not happen because a project is implemented. Instead, we must rely on indicators of what likely would have happened. The most objective way to assess whether a project is additional is to look at what others are doing outside of offset projects. If others in situations similar to the starting situation of the project do not take actions that the project takes to mitigate greenhouse gas emissions, then the resulting mitigation is additional and may count as an offset. If some others undertake similar activities and achieve atmospheric benefits, then the proportion of the project benefits that is additional is the proportion that is beyond the average of what is achieved by others with similar starting conditions. For example, if an owner of range lands afforests the land to sequester carbon, and 2% of other range lands are also afforested during the period within which the project occurs and sequester carbon at the

same per-acre rate as the project lands, then 2% of the project sequestration does not count as additional and does not count as an offset. The California Climate Registry forest project quantification protocols provide default rates of clearing, by county, for use in calculating baselines for forest conservation projects that avoid emissions from clearing of forests.

If an activity is legally required, then for the landowner it becomes the baseline activity. For example, if the state were to require new, wider buffer strips along streams where logging is prohibited, then growth of existing trees within the new buffer areas is baseline growth for the landowner. In contrast, if there is no regulation or contract preventing a landowner from cutting merchantable trees, then establishing a contract that prohibits the landowner from cutting those trees is in addition to the baseline, and simply maintaining the existing carbon stock might count as an emission offset (if the avoided emissions are not cancelled out by leakage).

In the last three years, California forest practice rules have required wider riparian buffers than previously mandated. A significant portion of the area encompassed by these new, wider buffers does not meet the stocking requirements of the state forest practice rules but for the areas that have been removed from the timberland base, landowners are no longer required to achieve the stocking levels required by the forest practice rules. For these lands, the baseline would be whatever growth would occur without stand enhancement efforts, and increasing stocking (and thus growth) to meet forest practice rule standards would be an additional activity above the baseline.

Leakage

If a project seeks to reduce emissions of forest carbon by stopping ongoing logging, and if the project does not accomplish a corresponding reduction in demand for wood products, then users of wood products will seek timber elsewhere. In most situations, other suppliers will make up most of the shortfall in supply with little change in the price of the good, and thus there is little change in consumption of the good. In the case of timber, this would mean that logging elsewhere would increase in response to a loss of timber supplied from project lands, and emissions from logging are thus displaced from within the project boundary to other locations outside the project. This displacement of emissions is called leakage. Calculating the net atmospheric benefit achieved by the project requires subtracting leakage from the gross benefit achieved within the project boundary.

The proportion of the reduction in supply of a good that is compensated for by other suppliers depends on the relative sensitivity of suppliers and consumers to changes in the price of the good. The rate of change in the amount of the good supplied as a function of a change in price is called the price elasticity of supply. The rate of change of the amount demanded by consumers as a function of change in the price of the good is called the price elasticity of demand. Over time, the supplies of manufactured goods and renewable resources are relatively elastic. This means that reductions in supplies of goods such as

timber are almost completely made up by increased production of other suppliers. For small reductions in supply, the replacement by other suppliers is more complete than for larger reductions in supply that can change prices. An equation for calculating the amount of leakage, as a function of price elasticities of supply and demand is given by Murray et al. (2004).

Because markets for wood products function fairly well, even moderately large reductions in supply are mostly compensated for by increases in production elsewhere, with the compensation being greater the smaller the market disruption. Even the large reduction in timber production on the west coast resulting from federal protection of the spotted owl resulted in about 85% of the supply reduction being made up by increased production in other regions (Murray et al. 2004). As a result, in California, one should expect that the leakage rate will be at least 85% for a forest conservation project that reduces the amount of timber supplied to markets without making a corresponding reduction in demand.

The existing requirement under SB 812 that only sequestration within California can be registered in the state climate registry does not affect leakage calculations because the main goal of leakage assessments is to account for emissions displaced by a project. These displaced emissions are not sequestration, and can be counted even if they occur outside of California. If existing rules are interpreted that displacement of emissions to outside of California does not have to be counted by California entities, then this problem will have to be fixed. Leakage may also be positive, where a project causes further emission mitigation outside the project boundary. If public decision makers believe a policy will cause positive leakage, they can consider that positive leakage when deciding whether or not to pursue the policy. This is not in conflict with SB 812. Further, existing California forest accounting protocols properly specify that entities may count their direct sequestration and emission reductions, and may not count sequestration or emission reductions that are direct to someone else and owned by that other entity. If positive leakage were to occur that is indirect to entities reporting in the California system, they would not be able to report it, regardless of whether or not it occurs in California.

Calculating leakage of emissions is complicated by the fact that the emission per unit of production of a good may be different for the suppliers that make up a shortfall than for the supplier undertaking climate mitigation actions. For example, if a project reduces timber harvest from a mature forest, it could displace timber harvest to a forest in a developing country, where inefficient logging practices result in greater emissions per cubic foot of timber produced. Alternatively, displacement could result in a reduction in emissions, even if the total amount of goods produced remains the same. For example, timber harvest could be displaced from a native forest with high emissions per cubic foot of wood extracted, to intensive plantations that have lower emissions per cubic foot of timber produced because the plantations have less carbon emitted from stumps, branches, and non-merchantable trees per cubic foot of timber extracted. Estimating whether leakage increases or decreases emissions requires careful analysis of the dynamics of the market for the good in question, and careful analysis of emissions per unit of production in locations to which production is displaced.

Reversibility

When carbon is stored in trees to mitigate greenhouse gas emissions, the trees can burn or rot, returning carbon dioxide to the atmosphere. In this way sequestration is reversible. Reversible offsets must be monitored for as long as they are used to mitigate emissions. This is accomplished by ongoing re-measurement and reporting of carbon stocks, as required under existing California Climate Action Registry forestry reporting protocols. If one wishes to stop monitoring a reversible offset, the reversible offset can be replaced with a permanent reduction in emissions. If sequestration used to offset emissions is reversed, the emission must be counted.

Activities Evaluated for Enhancing Carbon Sinks

This document does not recommend that California adopt specific policies. Instead, this document presents options that can provide at least moderate amounts of carbon sequestration in California, at a moderate cost, and seeks to describe the likely effects if each activity were supported by policy. It is left to policy makers to decide how much weight to give to each attribute, and decide which, if any, of these sequestration activities should be supported by policy. This analysis considers implementation of activities within the state of California. Implementing these activities both in and outside of the state of California could generate larger amounts of offsets at any given price or could generate the amounts of offsets estimated here for lower prices.

The activities evaluated here have been proposed by advocates as an activity worth supporting through public policy, or have been identified through analysis of the biological and economic opportunities existing in California land management. Analyzed activities are:

- Afforestation
- Thinning to promote forest health
- Burying biomass from forest thinning
- Thinning forests to reduce wildfire
- Converting hardwood stands to conifer
- Extending timber rotations
- Reducing conversion of forest to developed use
- Enhancing yard trees
- Increasing use of no-till cropping

Not all of these activities were found to mitigate greenhouse gas emissions, and some activities will mitigate emissions if implemented in some locations but result in emissions if implemented in other locations. The range of alternatives is presented to give policy makers an understanding activities that are physically possible and provide information on approaches that are being discussed in policy arenas. Some activities can mitigate emissions, but even if applied statewide would mitigate only relatively small amounts of emissions (Table 1). The activities that mitigate emissions for the lowest costs per ton CO₂ are activities that serve multiple goals, providing other types of benefits in addition to mitigating greenhouse gas emissions, such as timber, improving water efficiency of farming, or providing recreational areas or habitat.

Some land management changes can be combined with others, to get greater atmospheric benefit per acre. If land acquisition is part of the cost of implementing the activity, and two activities are compatible, then implementing both on a single site would reduce the cost per ton of mitigation because the land only has to be acquired once. However, if the activities are totally independent of each other, such as afforestation and extending rotations, then implementing more than one practice change on a site would have little effect on the cost per ton of emission mitigation. Some activity changes are incompatible, such as no-till cropping and afforestation.

Each activity has a different temporal profile through which it could sequester carbon. Analysis has sought to estimate outcomes that could be achieved by 2010, 2020, and where relevant, 2050. These analyses assume relatively rapid implementation of activities, but it would take several years to change land use practices across large areas and put lands on a trajectory toward achieving the benefits estimated in this report.

Carbon sequestration is only one value of many provided by lands. In most situations, carbon sequestration will not be the dominant value. Each land manager will have to consider his or her unique situation and determine whether or not carbon sequestration can be integrated with other land management objectives in a practical and holistic management regime. Considering the full range of land management goals is beyond the scope of this document; this document deals only with carbon sequestration.

Activity	Number of Tons	Levelized Cost/Ton	Notes
Afforestation	3.5 MMTCO ₂ e per year, average over 80 years.	\$6 to >\$70 depending on land cost.	Few tons for 10-20 years. Can reduce cost by thinning.
Forest health thins	3.7 MMTCO ₂ e per year, indefinitely.	<\$10	
Burying thinnings	9.5 MMTCO ₂ e per year, indefinitely.	\$24 to \$96	Cost depends on fiber price.
Thin to Reduce Fire	None	Not Applicable	Appears to cause net emissions
Convert hardwood to conifer	Cumulative, 70 MMTCO ₂ e over 45+ years.	\$10	No GHG benefit for 10-20 years
Extend rotations	0.7 MMTCO ₂ e per year for decades	\$110-\$140	No GHG benefit in first ten years
Reduce forest loss	0.9 MMTCO ₂ e per year for decades	< \$20?	Implemented via development rules
Enhance yard trees	< 0.1 MMTCO ₂ e per year?	Uncertain	Also reduces cooling demand
Increase no-till	3.8 MMTCO ₂ e per year for 15 years	< \$5 if by education \$100 if rental payments required	

Table 1. Number of tons and cost per ton of emission mitigation that might be achieved by selected land management changes. Color coding ranges from green for most desirable to red for least desirable. Note that high numbers of tons are desirable (green) while high costs are undesirable (red).

Each of the activities listed in the table on the previous page is discussed separately in more detail in the sections that follow. After the discussions of opportunities for implementing each activity is a discussion of selected policy issues involved in achieving

terrestrial carbon sequestration, including a discussion of how a cap and trade program could be created for forest terrestrial carbon sinks.

Afforestation

Afforestation is establishing trees on sites that are not currently forested. As the trees grow they remove carbon dioxide from the atmosphere, return most of the oxygen atoms from the carbon dioxide molecules to the atmosphere, and keep part of the carbon in their tissues. Approximately half the dry weight of a tree is carbon.

Initially, after planting, the carbon stock grows slowly because tree seedlings gain modest amounts of biomass. As trees grow and fully occupy the site, the rate of sequestration increases, and then slows again as the trees reach maturity. For long-lived species such as Ponderosa Pine and Douglas-fir, the carbon stock of the forest stand can continue to increase for hundreds of years, as long as the stand is not killed by logging, fire, or some other cause. In the absence of species change or major disturbance, mature and old forests can continue to slowly increase their carbon stocks, even as individual trees die and decompose, because new individuals are growing to take their places. A typical stand-level sequestration curve is shown in Figure 1.

In California, the rate of sequestration per acre, over the life of a project, can vary by nearly two orders of magnitude. Pine and Juniper woodlands support only scattered small trees, and may sequester only a few tons CO₂e per acre. In contrast, coastal redwood forests can hold more tree biomass than any other forest type on earth, sequestering over a thousand tons CO₂e per acre. Most of the state's forest lands are moderately productive conifer or hardwood forest although a substantial proportion are low productivity woodlands.

The afforestation scenario analyzed here assumes that the land is held permanently with no timber harvest, and thus no revenue from timber harvest accrues. It would be possible to manage afforested lands using uneven-age management methods, and maintain significant carbon stocks at all times. Also, it would be possible to manage a large block of lands for both sequestration and timber using even-age management, and have portions of the land in many age classes, and keep the total carbon stock on the lands relatively constant (once the regulated condition has been reached). Managing jointly for timber and carbon sequestration would provide revenue from timber, but would decrease revenue from carbon sequestration. The net effect of the trade-off between these two effects will depend on the average carbon stock stored, the time to reach that average stock, the amount of timber that can be removed, the timing of harvest, the value of that timber, and the value of greenhouse gas emission offsets. Site specific analysis would be needed to determine whether jointly managing for timber and carbon would increase or decrease the cost of carbon at that place.

A problem with afforestation projects is that the costs occur at the beginning of the project but most of the sequestration does not occur until years or decades later. Even

when the levelized cost per ton is low, the benefits do not accrue until years after the project is started.

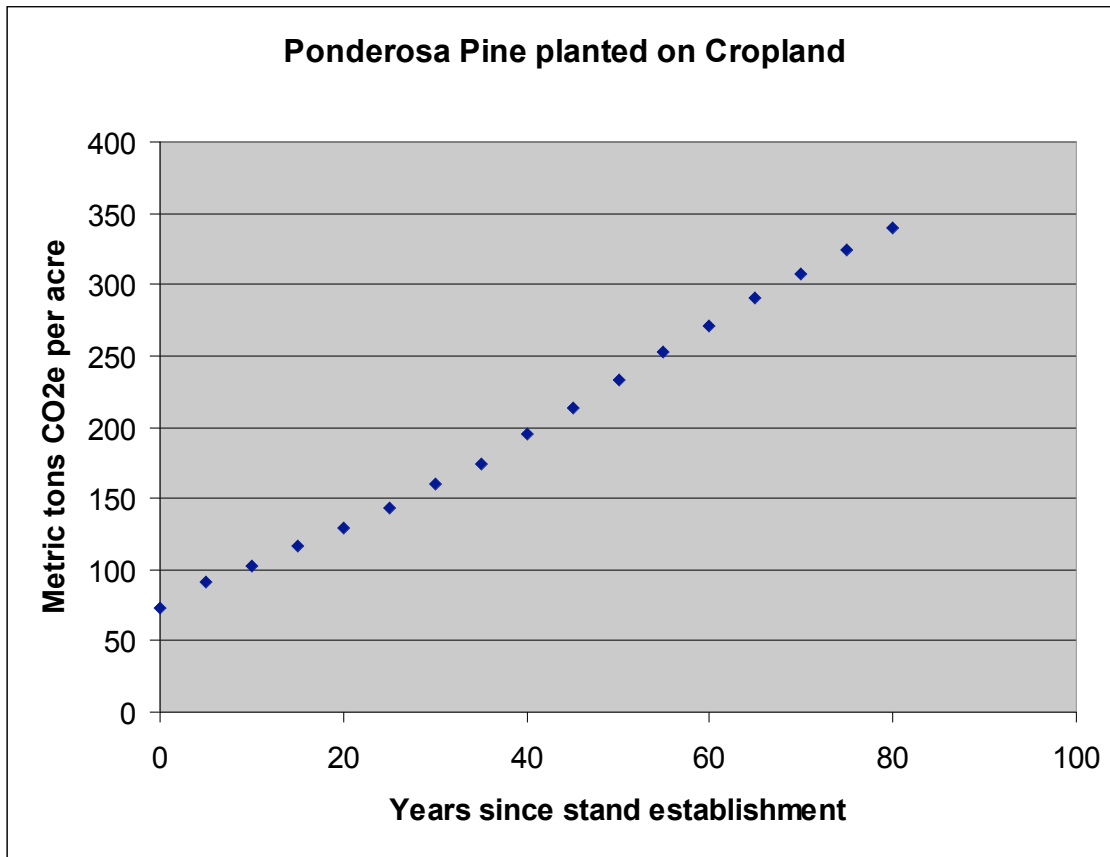


Figure 1. Average carbon stock in vegetation, detritus, and soil, after establishing Ponderosa Pine on cropland in the Pacific Coast region. Carbon stocks are calculated by Birdsey (1996).

The major costs of afforestation to sequester carbon are acquiring land and establishing the stand of trees. Maintaining the stand over time is relatively inexpensive. The cost per ton CO₂ of mitigation depends mostly on the costs of land and stand establishment, and how quickly trees grow. Because the value of land for development can be much higher than the value of lands for growing trees, lands with similar timber productivity but different demand for recreational or developed use can have hugely differing land values. Given that land price can vary tremendously, it is informative to evaluate the effect of the price of land on the cost per ton of greenhouse emission mitigation accomplished by afforestation. Table 2 illustrates the levelized cost of emission mitigation as a function of land cost. These calculations use the sequestration curve for average Ponderosa Pine shown in Figure 1, and assume establishment costs of \$450 per acre, and maintenance costs of \$8 per acre for the first five years after planting. Monitoring cost is assumed to be \$0.50 per acre per year. The land cost is assumed to occur in the first year of the project. This land cost can be the purchase of land, or can be the capitalized value of a stream of annual rental payments; the two sums are assumed to be the same and thus both yield the same estimated cost of mitigation. The analysis assumes that property taxes are

zero. Costs and benefits are tallied for the first 80 years of the project. Forest is assumed to continue growing on the site indefinitely, but gains after year 80 are not tallied.

It has been estimated that there are 23.6 millions acres of rangeland in California that are biologically suitable for afforestation (Brown et al. 2004a). Accounting for the varying productivity of these lands, on average, the lands were estimated as having a capacity to sequester 143 metric tons CO₂e per acre by age 20 and 653 metric tons CO₂e per acre by age 80 (weighted by area). For economic, political and ecological reasons only a fraction of these range lands could be afforested, but if all the apparently biologically suitable lands were afforested immediately, for several decades the growing trees would offset roughly 40% of the state's emissions, at the state's 1999 emission rate.

Land Price (\$/acre)	Levelized Mitigation Cost (\$/metric ton CO ₂ e)
\$0	\$6.21
\$100	\$7.50
\$500	\$12.68
\$1,000	\$19.15
\$2,000	\$32.10
\$5,000	\$70.94
\$10,000	\$135.67

Table 2. Levelized cost per metric ton CO₂e of sequestration from afforestation of cropland with Ponderosa Pine, as a function of land price.

Creating a large program to afforest range lands would increase demand for range lands, seedlings, and labor to establish stands. Increasing demand for these inputs would increase their prices, particularly if the program were to be implemented very quickly. Estimating how these input prices would change (and this increase the cost of resulting offsets) would require econometric modeling of shifts between market sectors and adaptation of supplies over time. This project did not have resources to do econometric modeling. Instead, this project estimates a supply curve by modifying supply curves given in a recent California Energy Commission report. The published curves were modified in two ways. One, instead of assuming that all land would be enrolled at once, it is assumed that land would be enrolled and planted over time, and that the supply of available land would be exhausted over a 40 year period. The second modification of the published supply curves is to increase the values assigned to lands. The published curves use land prices derived from the value of forage that might be produced on the land. The previously published values are substantially lower than observed California land prices, with values of most lands less than \$180 per acre. This analysis increases the contribution of the cost of land to the estimated cost per ton of sequestration by a factor of ten. Due to limits on the resources available for this analysis, this cost adjustment is based on anecdotal data rather than a survey of observed land sale prices. This supply curve does not take into account land price changes (in real terms) over time. Land prices are increasing faster than inflation, and a major new demand for range lands would speed price increases. This supply curve should be taken as a very rough estimate of the actual supply curve.

Even with much more realistic assumptions about land values, at a price of \$20 per ton CO₂e afforesting range lands is still estimated to be able to yield about 3.5 MMTCO₂e per year for 80 years, which would offset nearly 1% of the state's total net emissions at the 1999 emission rate. A caution is in order: afforestation projects require most of the costs to be paid near the beginning of the project, and these sorts of project yield little mitigation in the first decade after planting. Many rangeland sites are dry and trees would grow slowly. As a result, many rangeland afforestation sites would also yield only modest amounts of emission mitigation during the second decade after planting. The cost estimates presented here are levelized using a 4% discount rate, which means that the state could pay for land acquisition and planting by issuing bonds bearing a 4% interest rate, and pay off the bonds as tons are sequestered, and still pay the nominal prices per ton shown in Figure 2.

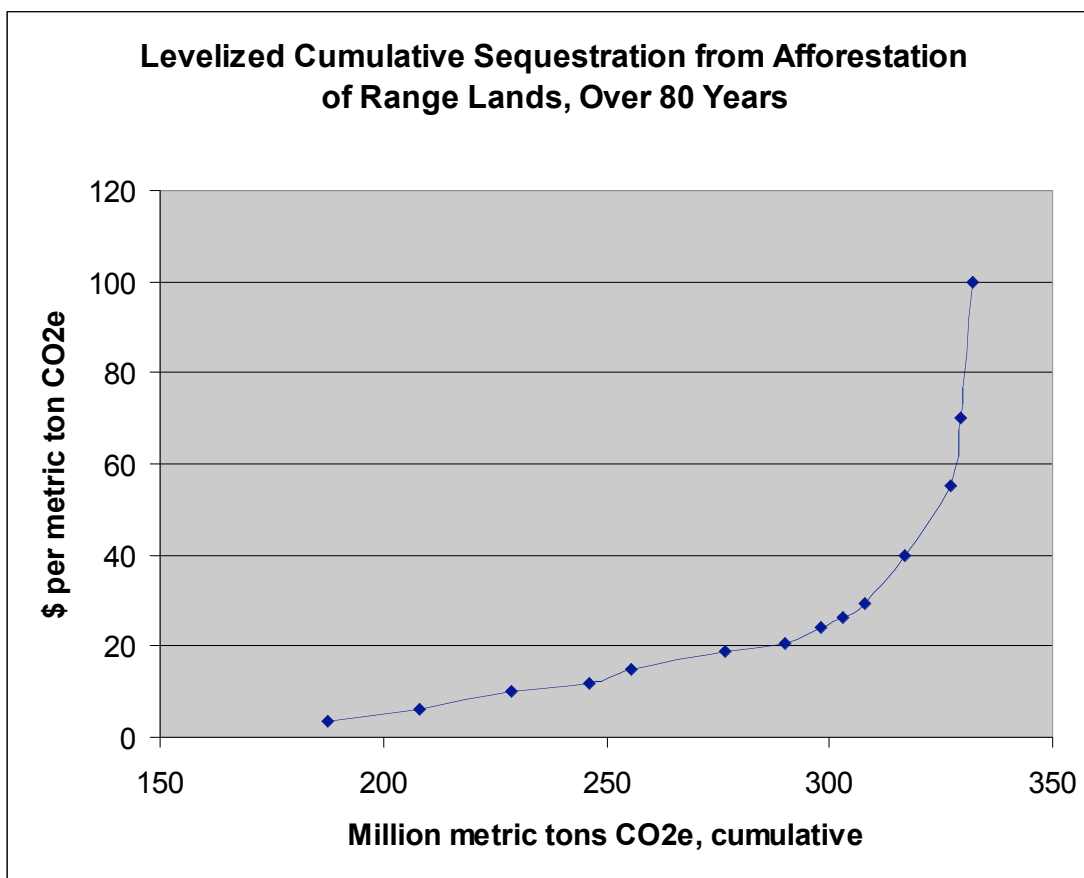


Figure 2. Levelized cumulative sequestration resulting from afforestation of range lands, over 80 years, as a function of price per ton CO₂e. See text for explanation of calculations.

Estimated Supply: 3.5 MMTCO₂e per year for 80 years (with fewer tons in the first decade or two) at a price of \$20 per metric ton CO₂e.

Electricity from Thinnings for Forest Health

The greenhouse gas benefit of this activity is created by using wood removed from forest thinnings to improve forest health as fuel in facilities that generate electricity, displacing electricity production from fossil fuels. For each megawatt hour (MWh) of power not generated by burning bituminous coal, approximately 1 MgCO₂e of emission is avoided. If oil is displaced, the avoided emission per MWh is about 0.8 MgCO₂e. If natural gas is displaced, the avoided emission per MWh is slightly less than 0.6 MgCO₂e.⁵

If, after thinning, average forest carbon stocks recover to their pre-thinning levels, then there are almost no net greenhouse emissions from the biomass. Typically, fuel used in hauling thinned material to the mill is on the order of 1% of the CO₂e value of the wood and displaced coal, and fuel used in logging is about the same.

However, if the average carbon stock of thinned stands does not recover, this decrease must be counted as a net emission. In effect, if forest carbon stocks are being permanently reduced, instead of mining coal and releasing the carbon in the coal to make electricity, one is mining wood and releasing the carbon in that wood to make electricity. The key is to find sites and thinning prescriptions that allow the average carbon stock, calculated over the thinning cycle, to remain constant or increase. It appears that on many sites in California, it will be possible to implement thinning prescriptions that will maintain average forest carbon stocks over time.

A large proportion of California forests and woodlands are forest types that evolved with a regime of relatively frequent, low intensity fires that reduced understory vegetation and left either widely spaced overstory trees or clumps of larger trees. Prominent types with this regime include Ponderosa Pine, many Oaks, and some kinds of mixed conifer. Decades of relatively effective fire suppression have reduced the annual area burned from several million acres per year to an average of 250,000 acres per year over the past 50 years (California Department of Forestry and Fire Protection 2003). Several decades of fire suppression have resulted in survival and growth of smaller trees across large areas of forest, to the point where the larger trees are stressed by the competition and are more susceptible to disease, drought, and fire. Also, if fires do get into these dense stands, the fires burn more intensely and are “laddered” by the crowns of the smaller trees into the crowns of the larger trees. Crown fires kill most or all of the trees in the stand, in contrast to ground fires that may kill small trees and the above ground parts of many shrubs, while leaving the larger trees. In overstocked stands that result from fire suppression, growth of the larger trees is slowed by the competition and death, and the risk that these trees will die prematurely is increased.

If the larger trees still have enough foliage to allow them to grow, removing much of the smaller vegetation can allow these trees to begin growing again (Oliver et al. 1996). California’s assessment of forests and rangelands concludes that, statewide, 20% of these lands are at risk of significant ecological harm from fire (California Department of Forestry and Fire Protection 2003). For most of the forest stands, there is risk of

⁵ US Energy Information Administration, <http://www.eia.doe.gov/oiaf/1605/coefficients.html>.

mortality from disease and fire susceptibility due to crowding, especially crowding by smaller trees. 20% of the forest land area of California is 8 million acres.

On many of these sites, especially conifer and mixed conifer forests, even mature trees can respond to thinning with increased diameter growth (Oliver et al. 1996). Thinning of young stands on productive Sierra sites has resulted in growth that replaced the removed basal area in three to seven years (Oliver et al. 1996). Total forest carbon stock is not linear with merchantable wood volume, but there is a significant correlation between the two. Harvest usually increases the amount of woody debris, and at the same time increases the rate of decomposition of woody debris. On less productive sites, it takes longer for the merchantable volume to return to pre-thinning amounts, often taking 10-15 years (Oliver et al. 1996). An analysis of stands at high risk of fire on the Fremont National Forest modeled thinning that removes all trees with diameters less than or equal to 9 inches from Forest Service Forest Inventory Analysis plots and estimated that carbon stocks would recover in 17 years (Mason et al. 2003).

For the average carbon stock to remain at the amount present immediately before thinning, the stock immediately before the next thinning would have to be higher than the starting amount. This higher level is required to balance out the decrease after thinning, to maintain the average at the level present prior to thinning. If thinnings are conducted every 20 years, careful analysis will be needed to find prescriptions that are silviculturally desirable that still maintain the average carbon stock.

The main limitation on thinning for forest health is lack of money. As a rough rule of thumb, for trees smaller than about 11 inches in diameter, it usually costs more than the value of the wood to cut them, get them to a road, and truck them to a mill where the wood can be used. Costs vary with terrain, stand densities, and other factors, but for many of these stands the cost of removing material up to 9 inches in diameter is in the range of \$300 to \$400 per acre (Mason et al. 2003, Glick 2005).

Commonly, thinnings in mixed conifer and Ponderosa Pine forests remove more than just the smallest, non-merchantable stems. Often thinning removes trees across the range of diameters present, including removing some larger trees that are commercially valuable for wood. Revenue from these larger trees can pay for the operation. Landowners have limited willingness to invest in thinning non-merchantable material, alone. This is particularly true on lands that are not managed primarily for timber, such as riparian reserves and other reserved lands. As a result, even if revenue can be gained from sale of merchantable trees removed in thinnings, substantial need remains for funding for reduction of non-merchantable biomass.

Using the material removed during thinnings to generate energy provides revenue that may pay for thinning work. This would require establishing new biomass energy plants near forests in need of thinning and near power lines, which would require private investment. Other analyses conducted by the California Energy Commission have investigated these issues.

A recent analysis of the biomass supply in California concluded that it is feasible to have a permanent supply of thinned material of 4.1 million dry tons per year (California Energy Commission 2005). If a demand for wood chips (for making paper) exists in the area, the amount available for energy might be small.

To calculate emission mitigation one must choose a reasonable emission rate for displaced energy. Biomass plants must run at a very high load factor to pay for themselves. As such, they are base load plants. After discussion with energy experts, this analysis assumes that the marginal base load plants that are displaced by a biomass plant are bituminous coal fired plants. Some analysts assume that the displaced emissions occur at the grid average emission rate, instead of analyzing what type of plants are the marginal energy suppliers. The Center for Clean Air Policy estimates that marginal emission rates in California over the next twenty years will average about 0.45 metric tons CO₂ per megawatt hour of energy supplied.⁶ The Climate Trust publishes emission factors calculated as an average of marginal and grid average emissions.⁷ The Climate Trust calculates emissions for the grid that covers most of California to be 0.5 metric tons CO₂ per megawatt hour of energy supplied, with the northeastern and southeaster corners of the state in grids that have emissions of approximately three quarters of a ton CO₂ per megawatt hour. If average forest carbon stocks are not reduced and coal is displaced, then generating electricity from material removed from forests during thinning operations would reduce emissions by 3.7 MMTCO₂e per year. This amount assumes that 0.98 Mg CO₂ is emitted per MWh generated by burning wood and 1.0 Mg CO₂ is emitted per MWh generated by burning bituminous coal. The emission reduction would be about 10% greater if anthracite coal is displaced, 20% less if oil is displaced, and 40% less if natural gas is displaced. If one were to use the Climate Trust emission factor for the California grid, the greenhouse benefit would be half the amount calculated here, and the costs per ton would be double the amounts calculated here. Using the Center for Clean Air Policy grid average emission estimate, the average benefits over the next two decades would be about 45% of the amount estimated here, and the costs would be about 2.2 times the amount estimated here.

Much of the cost of thinning could be paid by selling the material as fuel. However, on some sites, the cost of getting the material out of the woods to a road and trucking it to an energy generation facility will be greater than the value of the material as fuel. At recent power prices, an efficient facility can pay up to \$40 per short bone dry ton for wood chip fuel, and can make a profit when paying \$30 per ton (Jolley 2004). However, the cost of cutting material, hauling it to a road, chipping it, and loading it in a van for hauling is usually about \$30 per bone dry ton and trucking costs for a 30 mile (each way) haul can easily be \$10 per dry ton (Jolley 2004). For longer hauls, or steeper ground where logging costs are higher, another source of revenue would be needed in addition to biomass fuel revenues.

⁶ Matt Ogonoski, Center for Clean Air Policy, personal communication, September 2005. Calculation based on emissions estimated in the base case scenario of the US Energy Information Administration *Annual Energy Outlook 2005*.

⁷ www.climatetrust.org.

If wood is displacing coal, each bone dry ton of wood chips displaces about 1.8 Mg CO₂ of emission from coal. A \$5 per Mg CO₂ emission offset payment could provide \$9 per bone dry ton to pay for thinning or hauling costs. A \$10 per Mg CO₂ payment would provide \$18 per bone dry ton of chips. At the moderate rate of removal of 10 dry tons per acre, \$10 per Mg CO₂ would provide \$180 per acre in additional payments for thinning, in addition to the \$300 per acre that would be generated if a biomass energy facility pays \$30 per dry ton of chips. If the biomass is displacing natural gas, the greenhouse benefit would be 40% lower per ton of wood chips, and on a per acre basis revenues from emission mitigation would be correspondingly lower, for any given emission offset price.

Estimated Supply: 3.7 MMTCO₂e per year, indefinitely, at a price of \$10 per metric ton CO₂e or less (assuming coal is displaced; price is somewhat more than twice as high if grid average emissions are displaced).

Burying Biomass from Forest Thinning

Burying biomass removed from thinning operations can sequester more tons per acre than using thinned material for energy or wood products because landfills can sequester solid wood nearly indefinitely. However, burying wood forgoes revenues that could be obtained from selling the material for fuel or fiber. As a result, in most cases, this activity has a higher cost per ton of sequestration than thinning that sells the wood removed from stands. This activity is analyzed to provide a “bookend” to the policy continuum, where the rate of carbon sequestration is maximized regardless of the cost. As such, it provides a reference for comparison of other alternative practices.

As discussed in the section above, approximately 8 million acres of California forests are overstocked due to fire suppression. This forest health problem can be solved by removing the smaller trees from stands. However, until trees reach a diameter of about eleven inches in diameter at breast height (depending on species, how the trees have grown, terrain, distance to a timber mill, and fluctuations in the prices of wood products) it costs more to remove trees from the woods and truck them to a location where they can be used than is returned in revenue from products made from the wood. Due to limits on funds available for stand improvement, combined with the fact that many of the stands in need of thinning are in reserved areas that will never be commercially harvested to pay back investments, there are large areas in need of thinning.

This forest health problem provides an opportunity for mitigating greenhouse gas emissions. Wood from thinning forests could be sequestered in a landfill for an indefinitely long time. In a sealed landfill, this sequestration would be nearly permanent. Small emissions of methane during the first decades of storage can offset about 15% of the carbon dioxide equivalent of the stored wood (Skog and Nicholson 1998, 2000).

This activity would be more feasible if special burial areas can be created that do not require the containment required for landfills that hold municipal waste. Landfill space for municipal waste is scarce and expensive, and many states and municipalities across

the U.S. have taken steps to reduce the amount of material disposed of in landfills. Siting a new landfill can take a decade, and wood could fill existing landfills. Also, municipal landfills are generally located near populated areas. If wood is to be landfilled, it should be buried as close as possible to where it is cut, to reduce hauling costs. If typical landfill tipping fees are charged to bury wood in landfills, the mitigation provided this activity would be quite expensive. Even at a relatively moderate landfill tipping fee of \$20 per short ton, assuming that half of the weight of wood delivered to the landfill is water, this tipping fee would add \$24 per metric ton CO₂e to the cost of this activity.

A challenge arises because even the most thorough collection of thinned material still leaves on site a substantial amount of wood from trees killed by thinning. At minimum, stumps and roots are left behind. It may be desirable to retain foliage in the forest, to retain nutrients. Retaining foliage is generally accomplished by breaking branches off tree trunks and leaving branches in the woods. This material may have to be chipped or burned to limit fire risk, and California's fire control regulations require removing slash near roads. Removing branches from tree stems makes it efficient to move intact tree stems, which avoids the cost of chipping, allows efficient burial of material, and reduces decomposition of buried material. Removing only the stems of trees captures much of the carbon in trees. Thinning removes smaller trees and the boles of smaller trees contain a smaller proportion of the total carbon in the individual tree than in larger trees, but even in trees that are only a few inches in diameter more than half of the carbon is in the bole. Figure 3 shows the proportion of tree biomass in different tree components, as a function of tree diameter. Removing the boles of larger trees removes a larger proportion of the tree biomass, but removing larger trees can reduce the growth of the remaining stand. Removing the stem wood and bark of hardwood trees six inches in diameter or greater removes at least 54% of the tree biomass, and removing the stem wood and bark of conifer trees at six inches in diameter or greater removes at least 56% of the biomass.

If the growth of remaining trees does not replace the carbon emitted by decomposition of slash and forest floor disturbance, the net loss must be subtracted from the greenhouse benefit of sequestering wood in landfills. If the forest carbon stock does not recover, burial of logs merely transfers carbon from forests to landfills, minus emissions from slash and roots. If the stock partially recovers, there is benefit to the degree there is recovery (minus emissions from slash and roots). A decreased rate of benefit spreads costs over fewer tons and raises the cost per ton of emission mitigation.

No general rule predicts what will happen to forest carbon stocks after thinning. In general, treatments that leave the area stocked with vigorously growing trees may allow carbon stocks to recover in a few years. Slash and fine roots decompose quickly, often at rates of 10% to 30% per year, and wood often decomposes at rates of 5% to 15% per year (Harmon and Marks 2002). The net greenhouse effect depends on conditions specific to each site: the number, sizes and vigor of trees left after logging, the site quality, the degree of disturbance of logging, weather, and other factors. However, in most sites it appears possible to have a silviculturally desirable thinning prescription that allows the stand to recover lost carbon in a few years. If the carbon stock returns to the pre-thinning stock, then nearly the entire greenhouse benefit of the carbon sequestered in landfills

counts as a net greenhouse benefit. The greenhouse benefit of the buried wood is slightly reduced by the fuel used in logging, hauling and landfill operation. Typically, fuel used in all these activities will be no more than 4% of the greenhouse benefit of the buried wood, and often about 2% (Smith et al. in press).

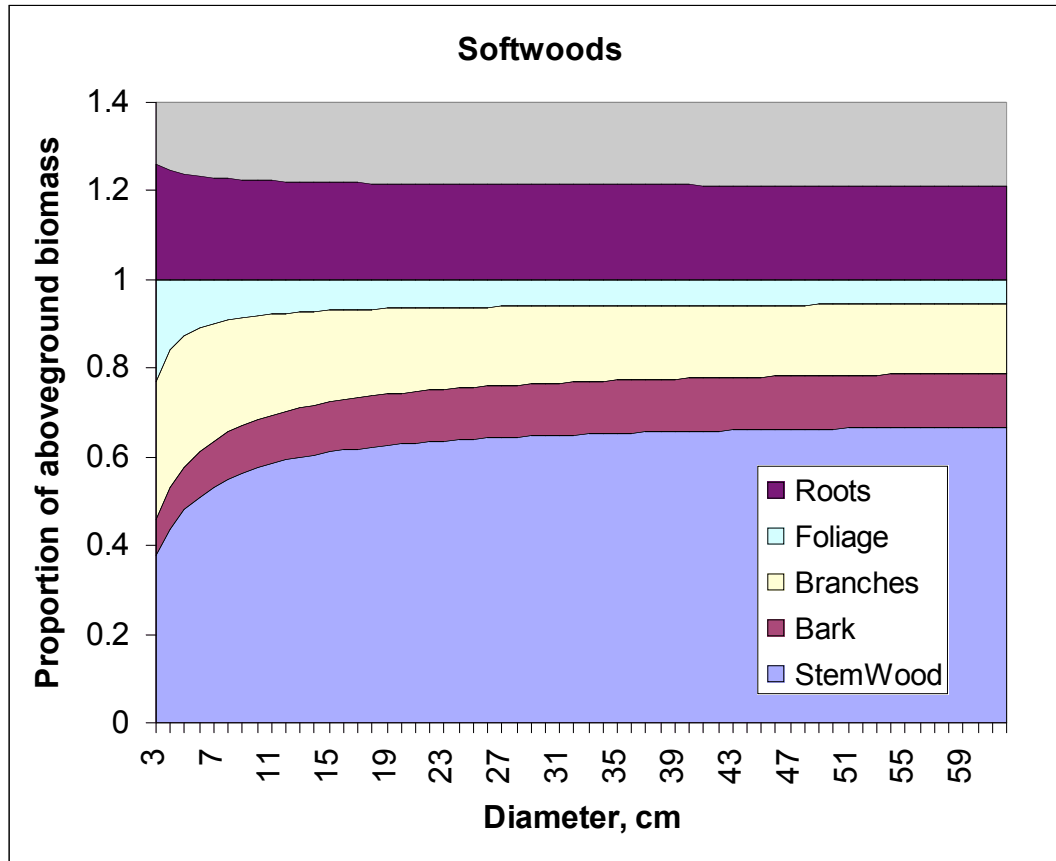


Figure 3. Proportion of softwood biomass in different tree components, for U.S. softwoods, as a function of tree diameter. Equations from Jenkins et al. (2003).

Over several thinning cycles, once the amount of carbon from a stand that is sequestered in landfills becomes greater than the amount lost from that stand when subsequent thinnings occur, then net sequestration continues even through periods shortly after thinning operations when losses from thinning are greatest (Figure 4). These calculations take tree carbon stocks from Birdsey (1996), for Ponderosa Pine in the Pacific Coast region. The figure assumes that 56% of the biomass of the thinned trees is buried, following Jenkins et al. (2003). Slash is assumed to be burned and residue is assumed to decay at a rate of 5% per year, following Harmon and Marks (2002). Over 20 years, emissions of methane and carbon dioxide from partial decomposition of buried wood are assumed to offset 15% of the sequestration value of the stored carbon (Skog and Nicholson 1998, 2000).

An advantage of burying material removed during thinning operations is that thinning is being done on a commercial basis, and landowners and contractors understand the

operations and are comfortable with doing them. No new technology or organizational structures are needed. However, implementing this activity would require creation of new burial sites. There are two reasons new burial sites would be needed. One, limiting costs requires limiting haul distances, so many sites will be needed that are distributed around the forest landscape. Two, urban landfills are expensive because of requirements for design, containment and monitoring (plus urban land costs are high), resulting in high costs per ton of material stored in municipal landfills. Wood should not need the containment and monitoring needed for urban waste, and burial sites that take only wood and are designed to hold the wood without decomposition should not be required to have the expensive containment and monitoring required for urban waste.

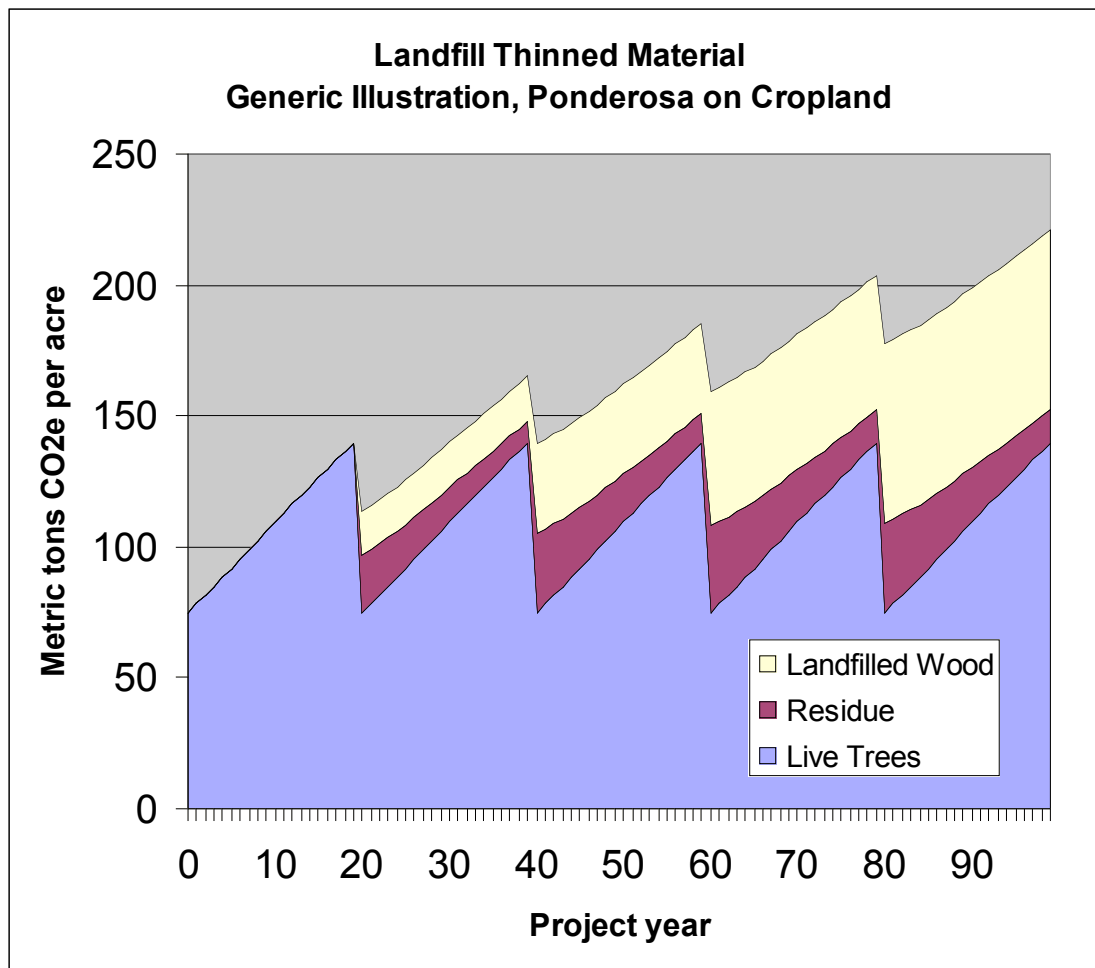


Figure 4. Thinning a Ponderosa Pine stand on former cropland, and burying tree boles removed from site.

Acquiring wood fiber for sequestering in a landfill may require competing in the market for fiber. Near paper mills and biomass power generation facilities, and at times when paper or power prices are high, there is enough demand for wood fiber that landowners require payment for wood that is removed by thinning operations. Farther from mills and at times when prices are lower, facilities pay less and these lower amounts may cover only the costs of extracting the fiber from the woods and hauling it to the facility.

Without payment for the fiber removed, landowners only allow thinning that increases the value of the remaining stand, by increasing the health, vigor or wood quality of the remaining trees. In locations farther from mills, at times when product prices are low, and on sites where steep terrain or long distances from roads make logging costs high, the costs of extracting fiber from the woods can be greater than what facilities will pay for that fiber. In these cases, no thinning is done unless the landowner is willing to pay for at least part of the work, to increase the future value of the remaining timber. This type of thinning is called “precommercial” and the cut trees are left in the woods to rot. Projects that bury thinned material could ask landowners to bid amounts they would pay to have the project come and thin their lands, and the project could accept the highest bids, thus defraying the costs of cutting, transporting and burying the material.

If wood can be buried at or near the location where it is cut, then hauling costs will be low. In sites far from existing facilities that use wood fiber, sequestration projects might be able to get fiber with no payment to the landowner, and pay only the cost of cutting, gathering, and burying the wood.

For reasons discussed above, the market price of delivered wood fiber varies tremendously, and the cost of delivering fiber to a point also varies tremendously. Smaller diameter trees require more handling per ton, thus increasing costs per ton delivered. Table 3 shows the effective price per ton CO₂e if fiber is paid for by the delivered green ton of chips. \$20 per short ton of chips provides a low estimate for possible costs. Only under favorable conditions would the cost of cutting material and loading it on a truck be at or less than \$20 per short ton of green material. Delivered chip prices vary hugely across time and parts of the country but are often in the range of \$40-\$70 per short ton. These prices indicate the price at which a biomass plant should be able to readily acquire fuel, although biomass plant builders seek locations and choose fuel types that allow them to pay less than \$40 per short ton dry matter.

This study did not have resources to do a GIS analysis of stand conditions, considering distance from roads and distance from facilities that buy wood fiber. Previous GIS studies looking at supplies of wood fiber have looked at either specific local areas or amounts of material available within a given distance of existing facilities that use biomass. The low-cost fiber for sequestration would be from locations that are too far from an existing facility that uses wood fiber to pay the cost of hauling the fiber to the existing facility. In general, usually the cost of hauling makes fiber not cost effective if it is more than 50 miles by road from the facility that will use it, and only in rare circumstances can facilities pay to haul fiber 80 miles or more. Low cost supplies of fiber for carbon sequestration would be on flat or gently sloping terrain, near roads, and not more than 50 miles by road from an existing facility that might purchase the fiber. However, it appears that substantial areas of forest are in need of thinning and near a road but far from an existing biomass plant. A recent study of biomass in California concluded that 6.7 million dry tons of biomass could feasibly be provided by thinning forests and chaparral (California Energy Commission 2005).

Delivered Green Chip Price	Delivered Chip Price	Cost per Metric Ton CO ₂ e
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(\$/short ton)	(\$/bone dry short ton)	Stored
\$10	\$5	\$12
\$20	\$10	\$24
\$30	\$15	\$36
\$40	\$20	\$48
\$50	\$25	\$60
\$60	\$30	\$72
\$70	\$35	\$84
\$80	\$40	\$96

Table 3. Conversion of costs between green chip price, price per bone dry ton, and cost per metric ton CO₂e stored. This table provides the cost of material, per ton CO₂e stored, as a function of the price of green or bone dry chips delivered to a burial site. Assuming 50% of green chip weight is water and that half the dry biomass weight is carbon and assuming that all of the carbon in wood chips is stored. These costs do not include burial costs.

As illustrated by Figure 4, the greenhouse benefits of thinning depend upon the time horizon over which emissions and sinks are counted. If one looks at a period of five years or less, thinning projects will cause net emissions because decomposition of logging debris will almost always be greater than regrowth of the remaining forest stand. If one looks out many decades, the amounts of carbon in material stored from multiple thinnings should more than offset reductions in carbon stocks within forests resulting from thinning. The more healthy and vigorous the stand left after thinning, and the lighter the thin, the more quickly the activity will yield net sequestration rather than net emissions.

The amount of potential emission mitigation from this activity can be calculated from estimates of amounts of material available for biomass. Assuming 6.7 million short dry tons of biomass per year from forest and chaparral thinning (California Energy Commission 2005), biomass is half carbon by dry weight, 15% of the sequestration accomplished by burying wood is offset by methane and carbon dioxide emissions from partial decomposition of the buried wood, and recovery of carbon stocks on thinned lands, 9.5 MMTCO₂e of mitigation could be achieved per year. The accrual of mitigation would lag several years after stands are treated, with mitigation accruing as the stands recovered the carbon lost during thinning. The estimate of supply is low if forests on steeper ground can be thinned, and is high if chaparral sites will have permanently reduced carbon stocks.

Estimated Supply: 9.5 MMTCO₂e per year for an indefinitely long time period (except few tons in the first decade) at a price of \$25 to \$95 per metric ton CO₂e.

Thinning Forests to Reduce Wildfires

Several parties have proposed that thinning forests to reduce wildfires can avoid stand-replacing fires, and thus reduce emissions to amounts less than what they would have been in the absence of the thinning. However, across the landscape, the limited existing

research does not support this view. The arguments for thinning have been based on calculations that an acre burned has greater emissions than an acre that is thinned. This is true, but when calculating the net effect across large landscapes other factors appear to dominate the net greenhouse effect. Reducing fire risk appears to require significant reductions in forest carbon stocks that are not made up for many decades, if ever. If it is possible to reduce fire risk with thinnings that allow the remaining stand to recover lost carbon in a few years, then it is possible that thinning to reduce wildfires might provide a greenhouse benefit.

In general, thinning to substantially reduce the spread of crown fires requires reducing the density of crown biomass, and risk also can be reduced by removing trees until the crowns of the remaining trees have significant air spaces between them. Other treatments that reduce fire risk are reducing amounts of fuel on the ground and creating a gap of several feet between ground fuels and canopy fuels. Reducing crown biomass density appears to require heavy thinning and removes a significant amount of the carbon present in an overstocked stand. Unlike thinning to maximize the growth of the remaining trees, thinning to limit the spread of crown fire appears to leave a significant portion of the area unoccupied by trees. As a result, thinning a few acres to a level that will limit spreading of crown fires causes emissions as great as one acre of fire.

Across the state, only about 0.2% of conifer forests and 0.4% of woodlands burn each year (California Department of Forestry and Fire Protection 2003). If a substantial percentage of the landscape must be treated to make a noticeable decrease in the extent of fires, the emissions from thinning are greater than several decades worth of avoided emissions from fire. The remainder of this section explains this situation in more detail.

The amount of biomass removed to reduce the risk of crown fire spreading will vary depending on the number and sizes of trees present before thinning, terrain, climate, and other factors. In general, because limiting fire spread requires both limiting the total density of fuel in the canopy to levels less than what is full stocking on all but the most unproductive sites, and is assisted by having gaps that hinder fire spread, stands thinned for fire resistance are less than fully stocked. In an analysis of mixed conifer forests similar to those in much of the Sierra, thinning from below to 45 square feet of basal area⁸ reduced fire hazard to low levels in most stands (Mason et al. 2003). The goal is to reduce the biomass of tree canopies to no more than 0.1 kg/m³ (Agee 1998, Graham et al. 2004).⁹ If trees are large enough to have significant amounts of heartwood, the stocking may be higher and thinning to 75 square feet of basal area reduced fire risk to low in

⁸ Basal area is a forester's indicator of the density of trees that accounts for the fact that one large tree requires several times as much space as a smaller tree. Basal area is the cumulative cross sectional area of all tree trunks present on the site, measured at four and one half feet above the ground, expressed per unit of area. "Thinning from below" means removing the smallest trees first up to a specified diameter or stand density. In uneven-age management thinning typically removes trees of all diameters, although it removes more trees of smaller diameter.

⁹ Reducing fire also involves increasing the height of the base of tree crowns and decreasing surface fuels, in addition to decreasing canopy bulk density and creating gaps between tree canopies (Graham et al. 2004).

some stands.¹⁰ In contrast, in many forest types that are adapted to frequent, low intensity fire, thinning to maximize total growth often leaves between 80 and 120 square feet of basal area. On productive, moist sites with a mix of shade tolerant and intolerant species and large trees, growth can be high even within stands having a basal area greater than 300 square feet per acre (Oliver et al. 1996).

Many stands that are at high risk of stand-replacing fire are overstocked. In an analysis of the Fremont National Forest, over 40% of stands at high risk of fire mortality had basal areas between 125 and 175 square feet per area, and nearly a quarter had basal areas greater than 175 square feet per area (Mason et al. 2003). As a result, thinning to a low stocking level, such as 45 square feet per acre, can remove approximately half the carbon stock present in vegetation. Even though the thinning may remove significantly more than half the basal area, often less than half the carbon stock is removed. This is because large trees have more carbon mass per square foot of basal area than small trees.

Even if merchantable material is used in wood products, much of the carbon in thinned trees ends up in the atmosphere within five years of the thinning. Stumps, roots, tops, foliage, and branches typically are left in the woods. Even if slash is not burned, nearly all the fine material will be decomposed within five years and the carbon in the decomposed material will mostly be returned to the atmosphere as carbon dioxide. If the material removed from the forest is used for paper, most of the stem wood is utilized. However, half of the carbon in sheet paper is estimated to be emitted in six years, and half of the carbon in non-sheet paper is estimated to be emitted in a year (Skog and Nicholson 1998, 2000). Most uses of bark result in relatively fast emission, including use as fuel in wood processing mills and use as landscaping mulch. If wood removed during thinning is used for solid wood products, the wood actually in those products can be stored for a long time, but more than half of the wood is converted to sawdust or other cutting waste and much of the carbon in this waste wood is emitted to the atmosphere within five years. Some wood waste is converted to particle board or other long-lived fiber products, but the proportion is modest.

If growth of the forest retained after thinning replaces the lost carbon, then the thinning has little net emission. Mixed conifer and Ponderosa Pine forests can have vigorous growth over a wide range of stand basal areas, with the total growth rate (in terms of basal area) having little relationship to the basal area of the stand. When many trees are present, each one grows a little bit. When few trees are present, each one grows much more. However, at some point, as basal area decreases, growth also decreases, because there is a limit to how fast an individual tree can grow. In general, when a significant proportion of the site is not occupied by trees, growth will be decreased relative to full stocking. Modeling mixed conifer stands at high risk of fire before thinning, where modeling thinned from below to 45 square feet per acre, after 30 years of growth, stand

¹⁰ Note that surface fires that are not in the crown may cause ecosystem damage (Graham et al. 2004). This analysis focuses on stand replacing fires because this type of fire causes the greatest release of stored carbon. Often stand replacing fires are crown fires but in stands with high surface fuel loads a surface fire can kill even large trees of fire-resistant species.

carbon stocks still averaged nearly thirty percent less than what was present at the time of thinning (Figure 5) (Mason et al. 2003).

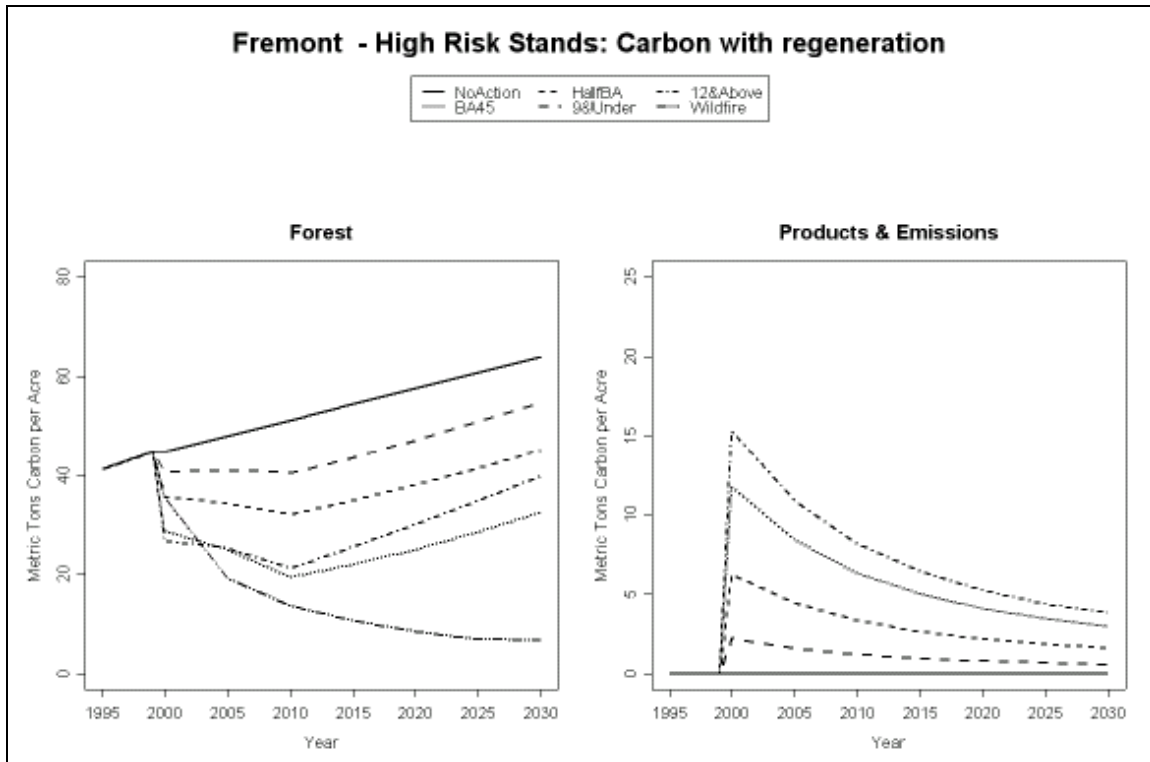


Figure 5. Average carbon stock and flow effects of different thinning regimes, on all stands at high risk of wildfire on the Fremont National Forest. The prescriptions removing half the basal area from below (halfBA) and thinning from below to 45 square feet of basal area per acre (BA45) were the only prescriptions that would get at least half the stands to low fire risk. Less intensive thinning did not reduce the fire risk on most stands below moderate. The low fire risk lasted 15 years and by year 2020 even stands treated with these aggressive thinning prescriptions needed further treatment to again reduce high and moderate fire risks. Reproduced from Mason et al. (2003), Appendix B.

To make the conclusion as robust as possible, this analysis uses extreme numbers for loss of carbon from fire, on a per acre basis, and lack of re-growth after stand replacing fire. This analysis assumes that all acres burned are burned intensely and do not grow back for decades. In reality, only about half the fires in the inland west on public lands (where a high proportion of the overstocked stands occur) are high severity (Graham et al. 2004).

Even after intense, stand replacing fire, usually more than half of the carbon present in the stand prior to the fire is still present on the site. This is because even intense fires burn almost none of the carbon in tree stem and root wood, and generally burn only a portion of the bark and branch carbon. Even if the forest floor and foliage is burned, the bulk of the carbon remains in tree stems and roots. On sites with unusually high amounts of carbon in the forest floor (such as many spruce forests in Alaska) or woody debris, fire can remove more than half the carbon on the site. If trees are killed in fire and not salvaged, they decompose over time. Most stands eventually regenerate after fire and at some point growth of new trees starts storing more carbon than is emitted by

decomposition of wood left after the fire. The exact proportion of stand carbon that is emitted during fire will depend on the intensity of the fire, the completeness with which it burns the area within the fire boundary, the size of trees, woody debris and litter carbon stocks, fuel moisture at the time of the fire, and other factors. Examining amounts of biomass burned in a variety of forests (Sandberg and Dost 1990, Walstad et al. 1990, Mason et al. 2003) suggests that a very, very rough rule of thumb is that in overstocked mixed conifer forests, fire will burn one third of the carbon present. The rate of decomposition of the carbon left in dead woody material after a fire will depend on moisture, temperature, species, size of pieces, whether or not the pieces are fire hardened, and other factors. A rough rule of thumb is that on many forest sites, decomposition will be in the range of 5% to 10% per year (Harmon and Marks 2002).

Given the fates of carbon after thinning and fire, even with stand replacing fire, 15 years after disturbance a little more than two acres of thinning to reduce fire risk emits as much carbon as one acre of wildfire. Thirty years after disturbance, assuming essentially no regrowth of the burned stand, emissions from three and one third acres of thinning equal the emissions from one acre of fire. During the first five years after disturbance, on a per acre basis, emissions are roughly the same for thinning and stand replacing wildfire.

Eventually, with re-establishment of trees and growth of the new trees, stands can recover carbon stocks to amounts present prior to fire. Obviously, the length of time of recovery will depend on the size of the stock present before the fire. Large starting stocks will take more time to recover. By definition, overstocked stands contain at least a moderate amount of carbon because they contain many trees. Even if none of the trees is large, the aggregate effect is that a significant amount of carbon is present. Applying biomass equations to USDA Forest Service Forest Inventory Analysis data showed that the average mixed conifer stand with high risk of fire on the Fremont National forest contained about 170 MgCO₂e per acre (Mason et al. 2003). Using standard tables for carbon sequestration (Birdsey 1996), it can take moderately productive Douglas-fir stands 38 years to gain this much carbon and can take Ponderosa Pine stands 100 years to gain the amount.

However, if the goal is to maintain a fire resistant landscape, fire-resistant stand conditions must be maintained over time. Timing of need for further treatment will depend on site productivity and other factors, but a review of the literature suggests that treatments will be needed at least every 20 years (Graham et al. 2003). As a result, carbon recovery will probably be slower than the rates given just above. Using standard biomass equations (Jenkins et al 2003), about a dozen 36" diameter Douglas-fir trees per acre would store 170 MgCO₂e per acre. At 12 trees per acre, the average tree spacing would be over 60 feet, leaving substantial gaps between tree crowns. However, few landowners will be willing to let trees grow to the very large diameters that would be necessary to contain carbon amounts equal to amounts in overstocked stands, while still retaining substantial gaps between tree canopies.

Moving from the stand to the landscape level, one must consider how many acres of fire might be avoided, and how many acres must be thinned to reduce fire. Over the past

several decades, an average of 0.4% of California woodlands burn each year, and 0.2% of conifer forests burn (California Department of Forestry and Fire Protection 2003). Reducing the rate of burning of conifer forest by half would reduce the fire rate by 0.1% of the forest area per year.

The question is what proportion of the total forest area would have to be thinned to achieve a 50% reduction in stand replacing fire? Crown fires have been observed to stop spreading when reaching thinned stands, but this research did not reveal any analysis that reliably showed the proportion of a landscape that must be fire resistant to reduce the rate of burning. Apparently no research shows that treatment conclusively reduced fire at the landscape scale, but it is widely believed that treatment can reduce the extent of fire (Graham et al. 2004). Large fires have been shown to be limited by naturally occurring areas that are less conducive to burning. Stand treatments to limit fire mortality can work. Large trees in treated patches have survived fires where large trees in adjacent untreated patches were killed.

Based on modeling of fire behavior, Finney (2001) asserts that strategically treating 20% of the landscape can reduce the spread of fire, and that strategically treating about 30% of the landscape could reduce fire by half (Figure 6). Finney's analysis suggests that even if all of the landscape is treated, still about 20% of fire would continue.

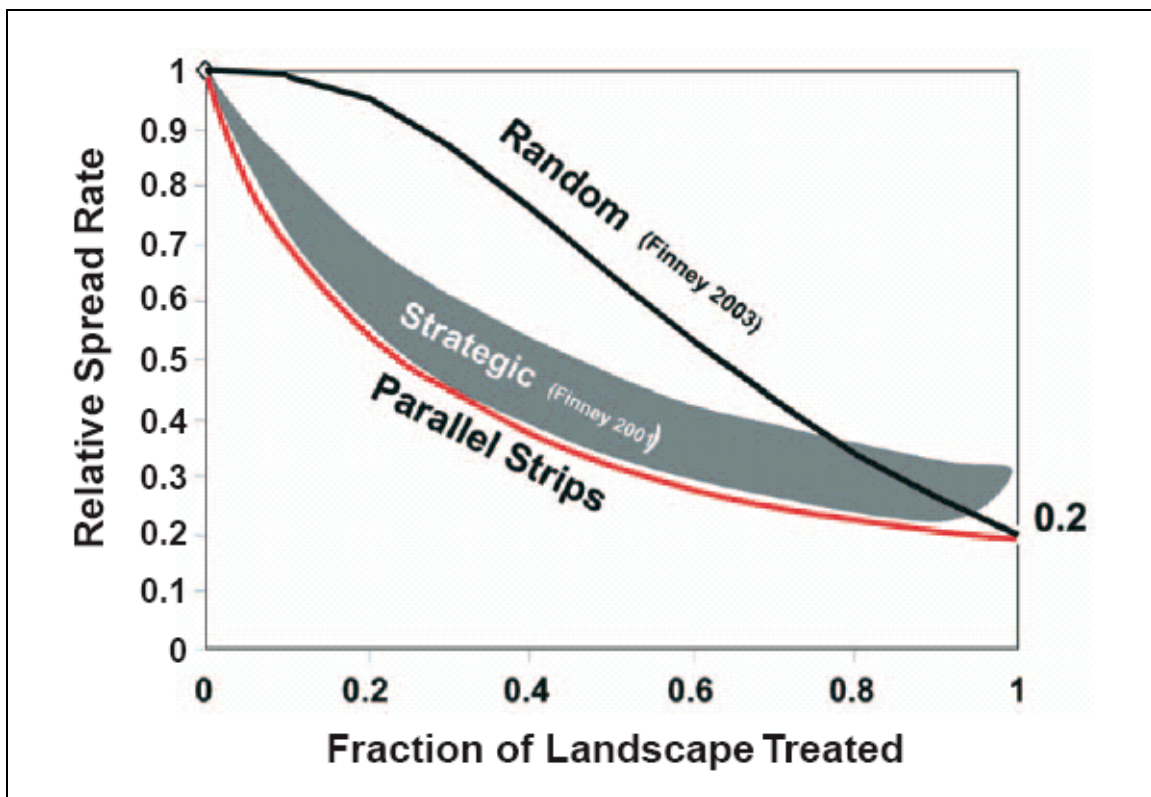


Figure 6. Theoretical reduction in fire extent achieved by treating forest to reduce fire spread. Reproduced from Graham et al. 2004.

If Finney's estimate is correct that 30% of the landscape would have to be treated to reduce fire by half, this area treated is 300 times the annual reduction in area burned, 0.1% per year. Assuming that treatment will have to be repeated every 15 to 20 years, if the analysis of Mason et al. is correct, 15 years after disturbance the emissions from about 1.5 acres of thinning will be equal to the emission from one acre of fire, and at 20 years after disturbance the emissions from 1.8 acres of thinning will be equal to emissions from one acre of fire. In 20 years, the proportion of the conifer forest landscape where burning was avoided would be 2%. Thinning 30% of the landscape to avoid this fire means treating 15 times the area of avoided burning. If 1.8 acres of treatment causes the same emissions as one acre of stand replacing fire, then the emissions from thinning are 8.3 times the reduction in fire emissions.

Estimated Supply: Apparently no net greenhouse benefit possible.

Converting Hardwood Stands to Conifer

Hardwood forests and woodlands cover nearly 10 million acres in California (California Department of Forestry and Fire Protection 2003). It may be both feasible and desirable to convert a significant fraction of these lands to conifer stands. Ecologically, it would be neither feasible or desirable to convert all hardwood areas to conifer.

Converting stands from hardwood to conifer causes emissions in the short term, from decomposition of wood from the former hardwood stand. Over time, per acre, growth from the new stand can store substantially more carbon than stored in hardwood forest (Figure 7.) On many hardwoods stands the stocking is low, so the emissions from conversion would be modest relative to the amount of carbon that can be stored by a conifer stand.

The cost per ton of sequestration achieved will depend on the revenue from merchantable hardwood material, costs of establishing conifers, whether or not the conifers are later thinned for revenue, and if so, revenue from future conifer thinnings. For tax accounting landowners must capitalize planting costs. For cash flow, if revenue from hardwood harvest pays for that harvest, taxes on the harvest, and the cost of establishing the new conifer stand, the landowner does not have to invest additional money in the conversion process. Costs of conversion may be significantly higher than costs of planting a clearcut without type conversion because of costs of control of competing vegetation, or the establishment of the conifer stand may be delayed by several years. The average stocking on hardwood stands in the state is 760 cubic feet per acre (California Department of Forestry and Fire Protection 2003), a low stocking level. Compounding the problem of the low typical stocking rate, there is little demand for hardwood in California and stumpage prices are low except for specialty grades. On the average stand, revenue from harvest probably will not come close to paying all the costs of conversion.

Using the standard numbers presented here, the new conifer stand achieves the carbon stock present in the former hardwood stand in the 20th year after treatment. If the carbon

stock in the existing stand is lower or the productivity of the conifer stand is higher, this point of restoration would come sooner. Similarly, if the carbon stock of the existing stand is higher or the productivity of the conifer stand is lower, it would take longer to reach the carbon stock of the original stand. This analysis is for an average California hardwood stand, which has only the timber volume of a well stocked, productive, even-age hardwood stand about 10 years old. If the site is a productive site, but has low stocking because of its disturbance history, over several decades, the site could achieve a net gain of a few hundred tons CO₂e per acre. During decades of peak growth, the carbon stock gain could be at the rate of 10 MgCO₂e per acre, undiscounted.

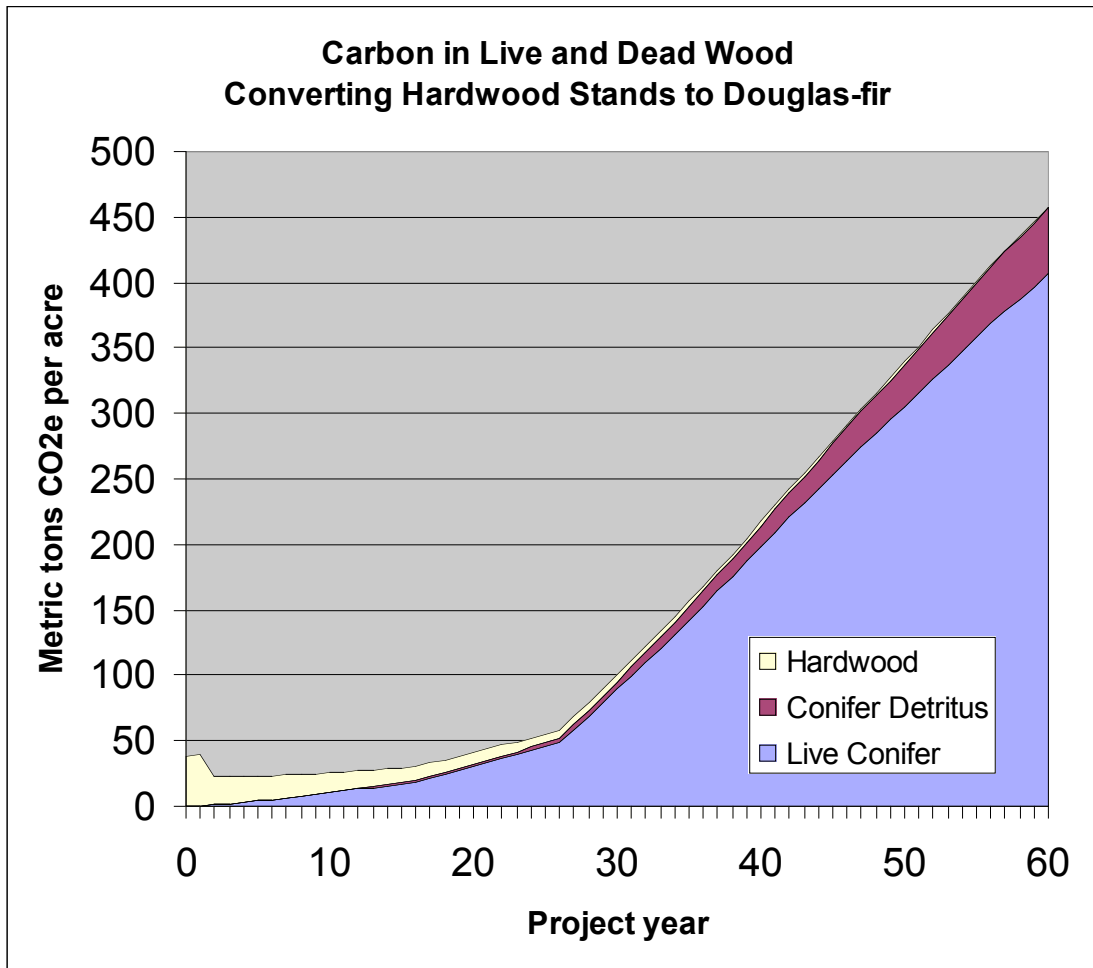


Figure 7. Carbon in live and dead wood, following conversion from hardwood to Douglas-fir, not counting carbon stored in wood products made from harvested hardwood. Assuming the hardwood stand has a carbon stock equal to that in an 11 year old even-age Pacific Coast hardwood stand and site index 60-78 Douglas-fir, with carbon stocks as calculated by Birdsey (1996). Conifer detritus production and decomposition rates from Harmon and Marks (2002).

If the treatment were to be applied in 2005, the discounted net gain in tons accumulated by 2050 is 70 MgCO₂e per acre, using an annual discount rate of 4%. If some entity is willing to pay now for these tons, the offset payment could be used to fund the conversion. Table 4 shows the implied discounted cost per ton CO₂e at different

conversion costs, with no discount for delivery risk. These general numbers should be confirmed with more site specific analysis of productivity before pursuing this option.

Cost of Conversion \$/acre	Implied Offset Price for 45-year Stream (\$/metric ton CO₂e)
\$200	\$3
\$400	\$6
\$600	\$9
\$800	\$11
\$1,000	\$14

Table 4. Implied cost of offsets, as a function of cost of stand conversion, cumulative for 45 years after treatment, discounted at 4% per year.

In conclusion, the primary challenge to implementing this activity appears to be finding a source of funding to pay for conversions. It is not clear how much landowner reluctance to invest in active timber management may also be a factor.

No net positive mitigation benefit would accrue until 10 years after stand conversion of a productive site with average stocking. If 10% of the hardwood area in the state can be converted, with subsequent growth at the rate calculated here, by 45 years after conversion, cumulative net positive sequestration would be 70 MMTCO₂e when discounted at an annual rate of 4%. The undiscounted amount would be 260 MMTCO₂e.

Estimated Supply: 70 MMTCO₂e cumulative by 2050 (but no tons in the first decade and few in the first 20 years) at a levelized price of \$10 per metric ton CO₂e or less.

Extending Timber Rotations

Extending timber rotations can sequester carbon because the average carbon stock on the site, over multiple rotations, increases as the rotation age increases. If costs and benefits are not discounted for the time value of money, then extending rotations up to the culmination of mean annual increment¹¹ increases the average revenue per acre per year. However, because of the time value of money, most commercial forest landowners prefer to harvest closer to economic rotation, which is the age at which the discounted average revenue per acre per year is maximized. Generally, the economic rotation is substantially shorter than the rotation that achieves culmination of mean annual increment.¹² It is this difference that makes it expensive to sequester carbon by extending rotations.

¹¹ Culmination of mean annual increment is a forestry term that may be applied to an individual tree or to a forest stand. In this usage it refers to stands. The annual growth increment is how much a tree or stand grows in one year. Culmination of mean annual increment is the age at which a tree or stand reaches its maximum growth rate, in calculated as standing stock divided by age.

¹² Culmination of mean annual increment is the age of trees at harvest, in an even-aged stand, where average wood volume growth is maximized.

This section will provide a simplified example and step-by-step description of how extending rotation age of an even-aged stand changes average yield, revenue, sequestration, undiscounted revenue per ton of sequestration, and discounted cost per ton of sequestration. The calculations could be done for an uneven-aged management scenario where the age of the oldest trees is increased. The math and growth calculations for an uneven-age example are significantly more complex, but the net effect is similar. Without discounting, increasing rotations increases average revenue per year and increases average sequestration. Without discounting, it pays a landowner to extend rotations beyond the legal minimum. With discounting, the value of the outcome reverses. The present value of revenues from longer rotations is lower than the present value of legal minimum rotations, and it becomes relatively costly to sequester carbon by extending rotations.

This example assumes starting with a 60 year old Douglas-fir stand on a relatively productive site, and calculates the effects of extending the rotation to 70 years. Yield and carbon stocks are from Birdsey (1996), for fully stocked timberland, using clearcutting and average management, for Douglas-fir on the Pacific Coast, for locations with a 50-year site index greater than 79.¹³ The Birdsey tables are particularly useful because they show both timber volume and total stand carbon stocks at different ages. In California, on Site Class II and III lands, the minimum harvest age for even-age management of Douglas-fir is 60 years, unless a forester can demonstrate that a shorter rotation meets a broader sustainable harvest goal. This example would extend the harvest ten years beyond the minimum age.

At age 60, Birdsey shows a yield of 13,143 cubic feet per acre, and at age 70 the yield is 15,355 cubic feet per acre. Following Brown et al. (2004a), cubic foot volume is converted to thousand board feet at the rate of 208 cubic feet per thousand board feet. In terms of thousand board feet per acre, the harvest at age 60 is 63.2 thousand board feet per acre and at age 70 the harvest is 73.8 thousand board feet per acre.

According to these numbers, the average annual growth rate is still increasing, from 1.053 thousand board feet per year with a 60 year rotation to 1.055 thousand board feet per year with a 70 year rotation. This calculation will slightly underestimate the increase annual yield from increasing the rotation age because as trees get older some larger logs are included in the harvest mix, and a larger log contains more board feet per cubic foot than a smaller log, and this calculation uses a constant rate of conversion of cubic feet to board feet, regardless of tree age. Actual data on log sizes would be required to more precisely calculate board feet.

Revenue from timber increases as the rotation length increases. Calculating the revenue per acre from harvest, assuming stumpage value of \$323¹⁴ per thousand board feet, the

¹³ Site index is a measure of site productivity. A 50 year site index of 79 means that the dominant and co-dominant trees in a 50 year old stand of trees will be about 79 feet tall.

¹⁴ This rate is the average rate across all regions of the state, for tractor logged Douglas-fir logs containing 150 to 300 board feet per log, calculated by the California State Board of Equalization for the second half of 2005.

revenue per acre with a 60 year rotation is \$20,410 and with a 70 year rotation the revenue is \$23,845. This is gross revenue from stumpage, before subtracting taxes, planning costs, and any other costs. More importantly, the revenue per acre per year is still rising as the rotation age increases, rising from \$340 with a 60 year rotation to \$341 with a 70 year rotation. Without discounting, it is financially beneficial to extend the rotation.

Discounting for the time value of money changes the financial effect of extending the rotation from positive to negative. At a 4% annual discount rate, if the stand is now age 60, the present value of the harvest at age 70 is \$16,109. The present value of harvesting the 60 year old stand today is the same as the nominal value, \$20,410, because the harvest is now. Deferring the harvest causes a decrease in the present value of \$4,301. If the landowner maximizing financial return (not determining harvest date for some other reason such as need for cash flow, keeping work flow even, or some other reason), a profit maximizing landowner would want to be paid \$4,301 today to defer the harvest of a 60 year old stand for ten years.

Extending the rotation age increases the average carbon stock on the land, which provides a greenhouse benefit. The levelized cost of obtaining this increase is calculated by dividing cost of the deferral (in present value terms) by the present value of the carbon benefit. This calculation requires calculating the average carbon stock under each rotation, determining when the carbon benefit accrues, and finding the present value of that benefit.

Extending the rotation on this stand does nothing to defer the demand for wood products that would have been served by the wood from this acre had the harvest gone according to the previous schedule of harvesting at age 60. Buyers continue purchasing wood products. Someone somewhere harvests a bit earlier than they would have otherwise, but we have no way of telling exactly who or exactly where. This is leakage and it approximately is equal to the deferred harvest. Other factors affect the ratio but the effects of these factors are small. When the stand is harvested at age 70 the wood is put on the market, displacing harvest by others, and canceling out the leakage that occurred by not harvesting at age 60. Again, other factors affect the ratio of displacement but these factors are small. The net result is that the greenhouse benefit accrues at the end of the rotation, ten years from now.

Average carbon stock is calculated by finding the carbon stock at numerous points at regular intervals through the rotation, summing, and dividing by the number of intervals at which carbon stock is measured or calculated. In this example, carbon stock was calculated every five years. The average carbon stock over the 60 year rotation was 444 MgCO₂e/acre and 497 MgCO₂e/acre over the 70 year rotation, a gain of 53 MgCO₂e/acre before levelizing. To calculate the levelized cost of achieving the greenhouse benefit, the gain that will accrue in ten years is discounted using the same 4% rate as for money, and the present value of the increase is about 35.8 MgCO₂e/acre. Dividing the discounted cost by the discounted tons gives the levelized cost of \$120 MgCO₂e. This amount

would depend on the productivity of the stand, and how the rate carbon accumulation changes as a function of stand age.

The offset price is obviously very sensitive to the discount rate used for the calculations. At a discount rate of zero, the landowner earns more by extending the rotation, even without any carbon payment. Some commercial firms use discount rates higher than the 4% used here, often in the range of six to eight percent. Using these higher discount rates would make the per-ton cost of offsets much higher.

In practice, this cost would be adjusted for other factors. For example, if the landowner saves money by being able to do fewer timber harvest plans, this could reduce the cost to the landowner, thus reducing the price of offsets. The California Forest Improvement Program has estimated that the cost per acre of preparing a timber harvest plan can be \$4.75, and reducing the frequency of harvest by one sixth would reduce these costs by one sixth. This simple example does not include costs of measuring carbon or writing contracts.

Other factors could affect the price paid per acre, but not affect the cost per ton of offset achieved. For example, concern that the tree growth may not occur as planned could reduce the price a buyer is willing to pay. On average, if the assessment of risk is correct, this price reduction does not decrease the price paid per ton of offset, because the amount of offsets actually accrued is less than the amounts predicted by the growth schedule.

Landowners do not always harvest at the legal minimum rotation age and this must be considered when designing a program to increase average carbon stocks. Potential buyers may be concerned that the landowner would not harvest the land at the minimum rotation age. This concern can be addressed by framing an offset purchase and sale agreement in terms of carbon stock present on the land. When the carbon stock is increased, and the landowner has returned to the previous level of wood production, then the carbon stock gain would be used to calculate the greenhouse benefit achieved. Under this form of contract, the landowner could do calculations of the sort presented here, to calculate the price at which the landowner would be willing to enter a contract.

Costs of extending rotations are estimated in a recent California Energy Commission report (Brown 2004a). Even for extensions of rotations of as little as five years, costs of extending rotations are almost always more than \$30 per metric ton CO₂e, and usually at least \$80 per ton CO₂e.¹⁵ This study assumed that low-cost tons could be acquired by contracting to extend rotations of hardwood stands. However, as the Winrock study correctly notes, hardwood stands are rarely managed commercially for wood products.

¹⁵ Note that when considering the cost estimates given in this California Energy Commission report, the correct method for calculating the costs is “Method 3” given in Appendix A of the report. As noted in the body of the report, this method most accurately represents effects on the atmosphere. The methods given in the body of the report are efforts to assign value to landowners by giving landowners credit for carbon stored in wood products that have been removed from the land and are owned by someone else as an offset, yet they do not count the carbon previously stored in stands that continues to be stored in living trees as sequestration. This asymmetry leads to inaccurate representation of emissions and removals of greenhouse gases.

As a result, many of the lower-cost tons projected by this study may not be available in reality.

The costs of extending rotations given in the California Energy Commission report are calculated assuming that landowners only need to be compensated for the time value of money of holding timber that could be sold. However, in reality, landowners also value the flexibility of being able to harvest stands when timber prices are high, or when they need cash flow. Because of these other factors that landowners value, many landowners may require payments higher than the time value of deferral of harvest in order to agree to defer harvest.

The California Energy Commission report estimating the supply of offsets from extending rotations estimates that softwood stands (which are often managed commercially for wood products) could yield about 0.73 MMTCO₂e at costs of \$110 to \$140 per metric ton CO₂e for permanent offsets. At prices several times higher, much greater amounts of sequestration could be achieved. These estimates are based on a financial analysis of the time value of money involved in deferring harvest. These estimates can be considered to be estimates of the “technical potential” of lands to sequester carbon, and not the “economic potential” to actually achieve offsets in a voluntary market. A recent study estimating the economic potential to achieve carbon sequestration with voluntary payments to landowners who commit to changing their land management practices found that the economic potential is often only a fraction of the technical potential, even at high carbon prices (Lewandrowski et al. 2004). If the situation is similar for extending timber rotations, the economic potential is somewhere between one quarter and one tenth of the technical potential sequestration estimated in the California Energy Commission report.

Estimated Supply: 0.7 MMTCO₂e per year (with no offset accrued in the first years) at a price of \$110 to \$140 per metric ton CO₂e; substantially more tons available at substantially higher prices.

Reducing Conversion of Forest to Developed Use

When forest land is converted to developed use, such as for housing or commercial buildings, most of the trees are cleared and most of the stored carbon is released. If development can be concentrated into a smaller footprint, a given number of dwelling units can be supplied with fewer acres cleared, avoiding some emissions from clearing.

The National Resources Inventory conducted by the Natural Resources Conservation Service concludes that from 1987 to 1997 California lost forest at a rate of 57,500 acres per year (U.S. Department of Agriculture 2000).¹⁶ This study is a comprehensive survey

¹⁶ The rate of conversion shown by NRI data from 1982 to 1997 was 38,000 acres per year. This lower rate is cited in the Department of Forestry 2003 forest and rangeland assessment. The higher rate is used here because it appears that future conversion will be more like conversion rates in the 1990s than like rates in the 1980s.

of non-federal lands and is probably the most reliable calculation of what is actually occurring across the state, because it is based on an extensive sample of observations of land cover at different times.

The opportunity for direct reductions in emissions from land clearing in California is moderate. The average carbon stock of California forests is about 160 metric tons CO₂e per acre in forest trees, understory plants, and the forest floor (Birdsey and Lewis 2003). It is likely that the carbon stock present on developed lands just prior to development is somewhat less than average because more development occurs on woodlands and agricultural lands than productive timber lands, but no analysis has been conducted to quantify the carbon losses on lands converted from forest to developed use. In the absence of data, this analysis assumes that lands converted from forest use have the state average carbon stock, and assumes that emissions from vegetation and soil during clearing are equal to the carbon stock in vegetation. If the area converted out of forest can be reduced by 10%, then emissions would be reduced by about 0.92 MMTCO₂e per year.

If development is displaced from forests to increased density in existing populated areas, then the distance people drive is probably reduced. An analysis of forest development in Washington State estimated that for each household displaced from forest conversion to other areas, emissions from driving were reduced by 2.5 metric tons CO₂e per household per year (Smith 2005).

Some people have questioned whether emissions can be avoided by reducing conversion of agricultural lands to developed uses. The answer to this question depends on (a) the relative emissions or sequestration of agriculture and conversion to developed use, and (b) the degree to which stopping agriculture on some fields causes an expansion of agriculture elsewhere. Crop lands have low carbon stocks and converting crop land to residential use has little effect on the carbon stocks present on the land, and may even result in an increase in carbon stock on the land resulting from people watering and fertilizing their yards, and thus increasing the soil carbon stock. Displacement may occur because land is being taken out of agriculture. If more agricultural goods are being produced than are being consumed at market prices (and the excess supply is acquired by government subsidy programs) and lands newly brought into agriculture are not eligible for subsidy programs, then little displacement will occur. If demand is displaced, but the displaced demand is served by intensifying production on lands previously in agriculture, the emission effects of the displacement should be modest. However, if displacement of agricultural lands results in clearing of forest land to create new agricultural land, then avoiding displacement of agricultural activities to new locations can avoid the emissions that result from clearing of new lands for agriculture. Reliably quantifying the emissions from displacement of agricultural production caused by development of agricultural lands would require several analytic components including analysis of the structure of the market for agricultural products, and econometric study of the dynamics of displacement between different agricultural products and between economic sectors. Conducting such an analysis requires more time and funding than was available for the analysis presented in this report.

Reducing the rate of conversion of forest land to non-forest uses would be largely addressed through zoning codes and development incentives. This would require working with counties to encourage developments that cluster more dwelling units into fewer square feet of land, and locate development near jobs and shopping. This is most easily done with large developments, and may be less successful when applied to lands that are already platted into parcels for one house each. If the permitting process is streamlined for designs that cluster development, this provides a significant incentive to developers to use the clustering option. An alternative strategy is to allow some developments that would not otherwise be allowed if the developer places a permanent conservation easement on other forest land, preserving an area that is a specified ratio of the area developed.

A benefit of this strategy is that mitigation starts accruing as soon as the clustering is achieved.

It is not possible to precisely estimate the costs of achieving this emission mitigation. Construction costs of clustered developments are generally less than the cost of building the same structures in a pattern that is not clustered. Cost savings are from reducing distances that roads and utility lines must be run, and costs of clearing land. Clustering takes more planning. It may be necessary to change county zoning codes to encourage clustering. Achieving zoning code changes generally requires working with county planners, zoning boards, and developers to build understanding and support for the concepts, and adapt model codes to each county. The main cost of achieving these benefits would be the cost of outreach and technical assistance programs to county officials and developers. A very rough estimate of costs would be several staffers (or consultants) for a few years. The cost of labor, travel costs, and printing informational materials should be no more than a few million dollars, spread over a few years.

Estimated Supply: Uncertain, but possibly 0.9 MMTCO₂e per year for several decades, probably at prices less than \$20 per metric ton CO₂e.

Enhancing Yard Trees

A single large tree can store several tons CO₂e. Encouraging landowners who have sufficient yard space to allow existing yard trees to grow large could store substantial amounts of carbon (Table 5). However, little is known about the incidence and survival of large yard trees. The little published information on yard and street tree mortality focuses on smaller trees. Surveys of urban canopy cover report total cover and this research did not reveal any inventories that distinguish numbers and sizes of large trees.

Costs of enhancing yard trees could be high or low, on a per-ton basis, depending on whether cost-effective mechanisms can be developed to communicate with candidate homeowners and get them to change their behavior. Education should address the value of carbon sequestration, how to prune trees to provide light to homes below them and increase windfirmness, and how to conduct hazard tree assessments. This program could

be publicized as a way for individuals to do something to prevent climate change, a sort of “victory garden” for the earth. A few large, fast-growing trees could offset the greenhouse emissions of a family.

Tree Diameter (inches)	Metric Tons CO ₂ e per Tree
36"	14.8
48"	29.9
60"	51.5

Table 5. Above and below ground sequestration by individual large Douglas-fir trees. Biomass calculated using equations from Jenkins et al. (2003) and assuming that biomass is half carbon by dry weight.

Also, in sunny, hot climates such as occur in much of California, yard trees can reduce household energy demand for cooling. These benefits have been estimated in other analyses and are not included here because the assigned focus of this analysis is carbon sequestration.

Lot sizes smaller than about one eighth to one quarter acre (depending on lot shape) do not have room for large yard trees. GIS analysis could determine the area of residentially zoned parcels larger than one quarter acre in size, and current vegetation could be assessed. Areas now in tree cover could potentially support larger trees.

Some homeowners do not let their yard trees grow large because they are concerned about the trees falling on their neighbors’ houses. If this concern prevents many homeowners from allowing their trees to become large, it is worth investigating whether an insurance program could solve the problem. With pruning and periodic inspection of the trees, the risk should be very low. The first thing to do would be to quantify the risk. If the risk can be kept very low, the cost of offering insurance could be assessed.

Estimated Supply: Uncertain but probably less than 0.1 MMTCO₂e per year for several decades. Price is highly dependent on the effectiveness of the program and could be high.

Increasing No-Till Cropping

For millennia agriculturalists have tilled soil to control vegetation that competes with plants and to release nutrients stored in the soil. One mechanism of releasing nutrients is breaking down soil aggregates and soil organic matter. Soil organic matter is about 58% carbon, and in productive soils this cumulative loss from tillage can be 60 metric tons CO₂e per acre in the top eight inches of soil. This loss of nutrients and soil structure decreases soil productivity. With new knowledge and technologies, many crops can now be grown without tillage. Ceasing tillage allows soil processes to restore some of the lost carbon.

Carbon sequestration in soil is a one-time opportunity. After reducing tillage, the soil carbon level rises toward a new equilibrium point that is a function of the new intensity of tillage, amounts of crop residue input, and other variables.

Some crops are not amenable to no-till management. For example, California regulations require shredding of cotton plant root crowns every fall, to control Pink Boll Worm. This regulation requires some soil disturbance to achieve effective root crown shredding, and the rule is incompatible with no-till practices. Research is underway to develop no-till practices for cotton in California.

The total opportunity for storing carbon, state wide, can be calculated by multiplying the area of crops that are amenable to no-till management but not currently in no-till management times the number of tons CO₂e per acre that might be gained. On highly productive soils switching from intensive tillage to no-till can sequester carbon at a rate of about 1.5 metric tons CO₂e per acre per year (West and Post 2002). It may be possible to sustain this rate for ten to fifteen years before approaching the new equilibrium soil carbon content. Considering the area in crops amenable to no-till and that it is extremely unlikely that use of no-till cropping practices will become universal, an upper-bound estimate of the potential for sequestration, across the state, is probably no more than 40 or maybe 60 MMTCO₂e, over ten to fifteen years, with average annual sequestration no more than 3.8 MMTCO₂e.

Estimates of the cost of implementing no-till range from negative (i.e. adopting the new practice would increase net farm revenue without payments for emission mitigation) to large costs. If annual incentive payments, such as payments made to farmers under conservation programs, are required to get farmers to adopt no-till cropping, the cost per ton would be substantial. For example, if farmers are paid a \$15 per acre annual incentive payment under a 15 year contract committing the farmer to not tilling, verification costs \$1.25 per acre per year, a total of 9 metric tons CO₂e per acre are stored over a 15 year contract, 40% of the farmers do not renew the contract and the carbon is lost, and the discount rate is 4%, then the levelized cost of maintaining an ongoing atmospheric benefit is \$97 per metric ton CO₂e.

Estimated Supply: Up to 3.8 MMTCO₂e per year for up to 15 years. Costs may be less than \$5 per metric ton CO₂e if farmers can be convinced to switch to no-till as a result of information provided by extension agents; cost can easily run to \$100 per metric ton CO₂e if annual incentive payments are required to get farmers to adopt no-till cropping.

Other Agricultural Practice Changes

A variety of agricultural practice changes have been proposed as ways to mitigate greenhouse gas emissions. These practice changes include:

- Reducing soil erosion
- Restoring grazing lands
- Changing crop rotations
- Adding winter cover crops
- Reducing nitrogen fertilizer use
- Altering cropping systems to reduce equipment use

Technically, these practice changes can mitigate greenhouse gas emissions in some situations. They are not addressed in this report in detail because of lack of data necessary to calculate potential state-wide benefit, or because the opportunities for greenhouse gas emission mitigation appear smaller than for increasing use of no-till cropping.

Other changes in agricultural practices can mitigate emissions, but are not addressed in this report because this report focuses on carbon sequestration and these other strategies do not involve carbon sequestration. Two promising strategies are (1) increased use of selected agricultural residues as a fuel source for generating electricity thus displacing fossil fuel, and (2) developing cropping systems that require fewer equipment passes across fields, saving farmers money and reducing fossil fuel use in equipment.

Reducing soil erosion from fields can cause significant increases in soil carbon stocks in those fields. However, reducing erosion has an unknown effect on net carbon sequestration over time. Much of the carbon lost from fields through erosion is not emitted to the atmosphere. Instead, much of eroded carbon is stored in deposition zones on land, in lakes, and in oceans. Also, because soil carbon stocks tend toward equilibrium, it is possible that, over time, if erosion were eliminated future transfers of carbon dioxide from the atmosphere to soil might decrease as soil carbon stocks reached equilibrium. There are substantial uncertainties about each of these factors, and the effects vary depending on the configuration of watersheds and other factors. Because of these uncertainties it is not yet possible to provide a reliable estimate of the greenhouse effects of reducing erosion.

Restoring grazing lands can increase soil carbon stocks. Conant et al. (2001) found that, on average, improving rangelands sequestered 0.79 metric tons CO₂e per acre per year, and that this sequestration can continue for up to 40 years. Studies have shown that improving grazing lands can improve total forage production, thus increasing the profitability of land management. A major focus of the Natural Resources Conservation Service and the Bureau of Land Management is improving the quality of lands. However despite all these factors, a large proportion of range lands remain degraded. Challenges to improving range land quality include the short term cost of decreasing current use while the land recovers, and the fact that better management of land often requires more attention and skill on the part of land managers. Given the history of this problem and the substantial federal resources already devoted to addressing it, it is not clear how much more the State of California could do to achieve the long-standing public policy goal of restoring range lands. Also, soil respiration increases caused by climate warming could cancel out much or all of the soil carbon gains achieved by improved management (Seastedt et al. 1994).

Changing crop rotations can sequester carbon, through a variety of mechanisms. The main opportunity for sequestering carbon through changing crop rotations is switching to crops that have higher amounts of residue, which provides a higher rate of input of carbon into soil. The higher rate of input of carbon causes a higher equilibrium between inputs and outputs, and increasing the soil carbon stock to the new equilibrium is sequestration. The amount of the increase in soil carbon over time will depend on the amount of the increase in carbon inputs in residue, tillage disturbance, climate, soil texture, and other factors. With continuation of conventional tillage, increasing crop residue inputs will cause little increase in soil carbon stocks, probably not more than 9 metric tons CO₂e per acre and probably more likely on the order of half or two thirds of this amount. On many fields, it is possible to grow any of several crops, and the farmer chooses which crop to grow as a function of the expected (or contracted) price of each crop, the equipment the farmer has access to, availability of crop processing and shipping facilities, and the farmer's knowledge of each crop. If different equipment is required to grow a different crop, the cost main cost of switching crops can be capital equipment costs, but may include labor costs or increased risk because of the farmer having less expertise about how to deal with problems in growing the new crop. Because of these costs of switching, one cannot estimate the payments farmers might require to induce them to switch from the difference in net return per acre from the different crops. Given these difficulties in estimating the price at which farmers would switch crops, this study does not attempt to develop a supply curve for sequestration generated by switching crops.

Adding winter cover crops to a cropping system produces more crop residue inputs to soil, and reduces the amount of time when soil respiration is occurring without plant inputs of carbon. As a result, adding a cover crop to a cropping system that uses fallow (summer or winter fallow) can increase soil carbon. However, rough estimates show that the price per ton of sequestration would be high. Assuming it costs only \$20 per acre per year to get a farmer to plant a cover crop (less than the cost of seed and two to four equipment passes across the field involved in adding a cover crop), and assuming a gain of 5 metric tons of CO₂e per acre over 10-15 years would result in a levelized cost of more than \$100 per metric ton CO₂e. If farmers require payments of more than \$20 per acre per year to add cover crops to their cropping system, the price per ton of emission mitigation increases roughly linearly as the rate of payments to farmers increases. Contracts obligating farmers to plant cover crops probably would not run more than ten years, or 15 years at the most. If farmers do not renew these contracts, and stop using cover crops after the expiration of a contract, the average amount sequestered per acre in the program will drop, further increasing the cost per ton. Also, water limits may constrain the area where adding a cover crop is applicable. Summer fallow is practiced because of water limits. If irrigation is needed to grow a cover crop, the emissions from irrigation generally will be greater than the sequestration by the cover crop. Even if net emission mitigation occurs with irrigation, the cost of irrigation would significantly increase the cost of sequestering carbon by adding a cover crop.

Other opportunities to reduce greenhouse gas emissions include improving the efficiency of nitrogen fertilizer use, reducing nitrous oxide emissions per unit of crop produced. Another approach to reducing emissions is to find ways to grow crops with fewer machinery passes across fields, this reducing emissions from fuel use. The purpose of this analysis is to examine carbon sequestration, so these opportunities are not investigated in this research.

Policy Issues

There are three conceptually very different approaches the State of California could use to achieve carbon sequestration in forest and agricultural lands:

- Require specific practices or technologies
- Public purchase of tons via auction
- Establish a cap and trade system

A fourth approach would be for the state to urge emitters to voluntarily reduce emissions, and for landowners to voluntarily increase carbon stocks. This is the approach that the federal government has taken for the past decade. Nationally, emissions have continued to increase. This approach of using verbal encouragement alone is not discussed here because experience has shown it to have limited effectiveness. Each of the three policy approaches discussed here would benefit from a public information campaign encouraging emission mitigation, but public information campaigns are not analyzed in this report.

These three policy approaches are compared and contrasted below. Also presented, under separate subheadings, are issues that policy makers should consider because they substantially affect the atmospheric benefit accrued by society, public spending, and the political acceptability of policies.

The choice of approach profoundly affects the number of tons accrued, the total cost and cost per ton, and who pays the costs. In general, landowners pay the bulk of the cost of regulations (often in the form of decreased economic returns from land), taxpayers pay the bulk of the cost of public purchases by auction, and under a cap and trade system those who pay are capped emitters and their customers.

Requiring specific technologies or practices can result in significant emission reductions or sequestration, but the cost per ton may be high. Properly designed cap and trade systems have delivered emission reductions for much less cost (Dudek et al. 1997). Public purchase of offsets by auction shares characteristics with cap and trade programs. However, while enforcement costs may be lower with public purchase programs, costs of setting baselines may be higher. Also, emitters may be more motivated to find internal emission reductions with a cap and trade program.

Policy makers are advised to consider the total cost of regulations borne by landowners. Forest landowners claim that the costs of complying with existing forest practice regulations are driving some forest landowners to convert their lands to non-forest uses. On the basis of the number of dollars per acre per year, returns from forestry are low relative to almost all other land uses, except for some agricultural uses. Costs of regulations do reduce the rate of return for a given land value, or reduce the land value for a given rate of return. In theory, as other uses for forest land are emerging, the lower the return from forestry the more quickly the land could shift to non-forest use. Counter to intuition, if lands shift from forestry to relatively large parcels such as 10 to 20 acre

home sites, over time carbon sequestration may increase. This is because few homeowners intensively manage large residential lots, and they may let trees grow longer than under intensive forest management. Analysis of the proportion of lots cleared as a function of lot size shows little increase the area cleared as lot size gets larger than about two acres, resulting in the proportion of the lot cleared decreasing as lot size increases (Smith 2005). If forest land shifts to small lots, reduction of forest carbon stocks generally occurs.

Require Specific Technologies or Practices

The State could require or prohibit specific technologies or practices. For example, the State could require no net loss of forest canopy as a condition of granting development permits, could increase minimum rotation ages for clearcutting, increase required amounts of basal area to be retained with uneven aged management, or prohibit specified kinds of tillage for specific crops.

If the required technology or practice is economically attractive relative to existing practices, but where landowners have not adopted the practice because of habit or transition costs, requiring technology might be a viable policy. For example, if no-till cropping truly does have economic returns equal to or greater than conventional tillage, and the reason that it is not widely used is because the technologies for making it work are new and farmers who are close to retirement do not want to invest in new equipment, learn new farming methods, and deal with the difficulties of rebuilding their soil quality, then a regulation could speed the switch to a new, better way of doing things. However, switching to no-till does require capital investment and does require more management intelligence than conventional tillage, and some farmers will not have the capacity to acquire and use no-till systems. These farmers would have to stop farming.

Requiring or prohibiting specific land management practices can achieve changes in land management across wide areas, with little investment of public dollars. Depending on the details of the new regulations, complying with new regulations can cost landowners small amounts of money or may cost private landowners large amounts of money. These costs could include outlays for new equipment, or could be lost revenues from activities that are no longer allowed. For example, if legal minimum timber rotations were increased, landowners would lose revenue from harvesting on shorter rotations that yield higher economic returns. It is often difficult to evaluate private costs imposed by regulations.

Drawbacks of requiring a specific technology are that the regulations do not stimulate development of still better technologies, and it is difficult to change regulations to adopt new technologies that are better than the required technology. Market systems, such as cap and trade programs, may avoid this problem.

Forest and agricultural practice requirements can be very politically contentious. Specifically, a few years back California had a politically heated struggle over a ballot

measure that would have prohibited clearcutting. The measure was defeated. There is no reason to think than a new measure to prohibit clearcutting would be any less contentious, even if the purpose of the new measure is to mitigate greenhouse gas emissions.

Requirements and prohibitions make the relationship between landowners and governments adversarial, and require the government to spend money on enforcement.

Ownership of emission reductions is not an issue when reductions are achieved via regulation. For example, if the State decides to require all new cars to emit no more CO₂e per mile driven than a specified standard, no one needs to pay attention to whether the emission reductions are owned by drivers, the company that makes vehicles meeting the standard, oil companies whose product was previously causing larger quantities of emissions, or someone else.

Voluntary Project-Based Sequestration

There are two ways terrestrial carbon sequestration could be included in a greenhouse emission mitigation program. One approach is to allow landowners to voluntarily generate and sell offsets, and the other approach is to require that landowners store a mandated amount of carbon. A system where landowner participation is voluntary would be similar to “Clean Development Mechanism” projects implemented in less industrialized countries under the Kyoto Protocol system for reducing greenhouse gas emissions. The alternative system, where landowners are required to store a specified amount of carbon on their lands, would be analogous to an emission cap for an industrial sector. This section addresses the first of these two alternative system designs, voluntary participation by landowners. The next section discusses the other alternative design, a mandatory cap and trade system for lands where landowners are required to achieve and maintain specified carbon stocks.

A major difficulty with voluntary projects is the problem of determining the appropriate baseline for each project. Land management and terrestrial carbon stocks often change over time, even when lands are not part of greenhouse gas emission projects. As a result, baseline carbon stocks change over time. The carbon stock present at the date of the start of an offset project is not necessarily the carbon stock that would have been present several decades from now if the lands had not been enrolled in a project. To establish a baseline for a sequestration project, one must estimate how the carbon stock on the lands would likely have changed had the project not been implemented.

The most objective way to estimate what the carbon stock on lands would likely have been in absence of the project is to look at what happens to carbon stocks on other lands having similar starting conditions. For example, suppose a landowner implements a sequestration project that sequesters carbon by growing trees on land that previously had been used to grow small grain crops. If all other lands in the vicinity that are used to grow small grain crops remain in small grain crops and sequester no carbon, then all the carbon sequestered within the project boundary counts as an offset (minus emissions

displaced by the project to other locations outside the project boundary). However, if all other lands in the region that were used to grow small grains are also converted to trees, then the baseline would be the average sequestration by the trees on these other lands and the baseline carbon stock would rise at the rate of sequestration observed on the non-project lands. It is possible that the baseline can rise as fast as the carbon stock on the project lands. If so, none of the carbon sequestered on the project lands would be above the baseline, and thus none of the project sequestration would count as an offset. If 10% of the other lands are also converted to trees (and all the trees sequester carbon at the same rate) then 10% of the carbon stored by the project would not be above the baseline and would not count as an offset. The California Clean Air Registry forestry protocols apply this approach to rates of conversion of forest land to non-forest use, for determining the rate at which forest conservation projects avoid emissions from deforestation. Baselines must also address displacement of emissions to outside the project boundary (e.g., leakage). For an extensive discussion of how to set baselines for terrestrial projects, see Smith et al. (in press).

Setting baselines requires work and is often expensive. It is challenging to determine what lands constitute an appropriate comparison. If a project has to pay for quantifying changes in carbon stocks on baseline lands, as well as project lands, the cost can be double the cost of only quantifying changes in carbon stocks on project lands.

If California is considering an emission mitigation system where landowners can voluntarily implement projects that sequester carbon, the State should examine the feasibility of developing baselines for selected activities occurring in selected regions. These baselines would be available for use by any project of the appropriate type and in the appropriate region. Standard baselines would reduce the cost and uncertainty faced by projects. Also, standard baselines would reduce the opportunity for projects to “game” the system by selecting inputs to calculations to show low baseline sequestration, to have more of the carbon within the project boundary count as offsets. On the other hand, using a standardized baseline may miss project-specific deviations from the average, such as lower amount of sequestration being achieved by selectively enrolling low productivity lands in offset projects.

This problem can be avoided by measuring actual project achievements. Experience by the third party verifiers of terrestrial carbon sequestration, the Environmental Resources Trust and Winrock International, show that aggregating lands into blocks of a few thousand acres each can spread measurement costs over large numbers of acres so that the cost per acre can be cents per year.

Finally, from a GHG mitigation standpoint, a main downside to voluntary project-based sequestration is that participation is voluntary. Landowners that were already planning to make modifications to their management practices for other reasons are more likely to participate in the program, and those who are reducing the carbon stocks held by their lands are unlikely to participate in a voluntary program. If forest and agricultural landowners may voluntarily create offsets and sell these offsets to capped emitters in other business sectors, and if these land-generated offsets are based on sequestration that

would have happened anyway, then the net effect on the atmosphere is to reduce the amount of net emission reductions that otherwise would have occurred under the cap.

When considering voluntary programs, policy makers should consider whether or not many landowners are likely to participate in a voluntary program when offset prices are modest. For example, when development value for forest land exists, or when a fair amount of merchantable volume of timber exists on a property, few landowners will be willing to commit to increasing forest carbon stocks and holding these increased stocks for ever, unless the offset price is extremely high. This is because at low offset prices the per-acre value of offsets would be small relative to the per-acre returns possible from other uses such as development or logging. If maintaining the carbon sink is perceived as limiting land management options (such as limiting the opportunity for the landowner to sell the land for non-forest use or draw down standing timber volumes), few landowners will be willing to voluntarily take actions for payments that are only a tiny fraction of the value of the land plus existing timber. For example, even if a landowner could store an additional 50 tons per acre and get paid \$10 per ton (\$500 per acre) few landowners would be willing to commit to this on an acre of land where the land and timber are worth \$10,000 (or possibly much more), and where the sequestration contract is perceived as reducing the future value of the land. Afforestation projects might not have this problem because the per-acre value of offsets can be substantial relative to the price of land.

Private Purchase of Voluntary Offsets

A system where landowners can voluntarily choose to create and sell greenhouse gas emission offsets could be designed such that the offsets are sold either to the state or to greenhouse gas emitters regulated under a cap and trade system. This subsection addresses private purchases by regulated emitters. The next subsection discusses a program where the State would purchase offsets.

In a private purchase system, voluntarily generated offsets would be sold into a cap and trade system. In a cap and trade program, a regulatory agency determines what emitters must participate, and the regulator sets the total amount of allowable emissions during each accounting period. Typically, regulated emitters must count their emissions and submit one valid allowance to the regulator for each unit of regulated material the emitter emits within each accounting period. Also, the regulator distributes the allowances. Most often, allowances are given to emitters as a proportion of their emissions prior to the start of the program, possibly with some adjustments. This approach to distributing allowances is called grandfathering of emissions. Economists note that it is most efficient for the regulator to auction at least a portion of the allowances, but grandfathering is much more palatable to emitters so most programs use grandfathering. The “trade” part of the cap and trade system describes the fact that efficiency is achieved by allowing emitters to sell or trade allowances among themselves, so that the reductions are achieved by the entities that can make the reductions most cheaply.

Allowing landowners to create emission offsets and sell these offsets to regulated emitters for those emitters to use to comply with emission caps is, in essence, allowing landowners to create a type of allowance. Offsets must be real, or the extra emissions made possible by the offsets will not be mitigated by a physical removal of greenhouse gases, and the cap is eroded.

Further, if the physical sequestration of carbon underlying an offset is reversed, the offset must be counted as lost and the amount of the emission counted in the account of the user of the offset. For example, if an offset is created by sequestering carbon by growing trees, and the trees burn and release the carbon back into the atmosphere as carbon dioxide, the offset disappears. The forestry protocols of the existing California voluntary emission registry accomplish this by requiring periodic measurement of terrestrial carbon stocks, and reporting changes in stocks. This reversibility of terrestrial offsets means that they must be monitored to verify their continued existence for as long as they are used for compliance with an emission cap. If an emitter who has used a terrestrial offset as compliance wishes to stop monitoring the offset, the emitter should replace the reversible offset with a non-reversible allowance or offset.

If a regulated emitter has surrendered a reversed offset as part of compliance with an emission cap, the emitter that used the offset must book an emission of the amount of the lost offset. Alternatively, emitters could choose to purchase offsets that are guaranteed by the supplier, so that the supplier replaces any offsets that are reversed. Another strategy for dealing with this problem is insurance. If available, insurance could replace reversed offsets with different offsets, or pay for purchase of replacement offsets on an open market for offsets.

One way to design an offset program would allow the full value of the offsets generated to be sold into the trading system. Under this scenario, no additional reductions would be achieved beyond the cap-and-trade program. The offset simply makes it less costly for regulated emitters to comply with the cap. Another way to design an offset program would require retirement of a portion of each offset, ensuring that some additional reductions are achieved beyond a cap-and-trade program applicable to other sectors. However, reducing the offset value would be expected to reduce voluntary participation in the offset program. A third way to design an offset program would be to allow the full value of offsets generated to be sold into the trading system, but also require that all private and non-Federal public landowners also surrender allowances to compensate for net deforestation over a threshold level. This is a cap on forest carbon emissions (with the cap set at zero) and is discussed separately below. Under any of these scenarios, discounting might be considered to account for uncertainty in measurement and monitoring.

State Purchase of Voluntary Offsets

Instead of establishing an emission cap for emitters that meet specific criteria, the State could purchase offsets directly from entities that create the offsets. These purchases

would result in emissions reductions that are additional to other regulatory and other GHG mitigation programs and would help the State meet a greenhouse emission target.

To find the lowest cost offsets, the State could purchase atmospheric benefits through public auctions. These purchases could be for emission mitigation from any source within the state¹⁷ (reducing industrial or transportation emissions, sequestration from land management, or other sources) or could be limited to a single sector or practice (e.g. farmers bidding how much they require to be paid to switch to no-till cropping and continue using no-till practices). Public auctions give landowners and others an incentive to seek out the cheapest sources of emission mitigation, and develop new methods for mitigation.

Because bids and contracts are completed before practices are implemented and emission mitigation is achieved, purchasing emission mitigation via auction requires estimating benefits before activities are implemented. Estimation can be problematic. When the amount of atmospheric benefit is a function of land productivity, an independent third party may not have the information necessary to estimate future atmospheric effects of performing specified management activities. When production of atmospheric benefits correlates to production of economic goods, the asymmetry of information between the landowner and reviewer of bids can lead to an incentive for adverse selection. For example, lands that produce higher crop yields generally can sequester more carbon than less productive lands. If mitigation payments are pegged to behaviors (such as converting land from tilled crops to pasture) rather than measured amounts of sequestration, and if economic returns to landowners from carbon sequestration are modest relative to economic returns from other uses and sequestering carbon reduces revenue from other uses, then landowners will be most interested in selling carbon sequestration on lands that earn little from other uses. Continuing the example of converting crop lands to pasture, this would be stopping tilling unproductive lands that both return less revenue from crops and will store less carbon. If a third party knows less about the productivity of the land, the third party may not be able to tell that the offered lands will sequester little carbon.

Further complication of estimation of benefits occurs when the amount of atmospheric benefit achieved depends on the quality of land management activities (such as how well sites are prepared for planting or how well seedlings are planted). In such cases, some sort of verification of the quality of outcomes is needed. For example, for an afforestation project, part of the payment can be withheld or a lien can be placed on property until a specified number of trees per acre are established and certified as free to grow. Ideally, verification would measure amounts of sequestration or emission reductions actually achieved over time.

Another issue in purchasing emission mitigation by auction is assignment of risks that project outcomes will not be as desired. For example, disease or wildfire can prevent a young forest from sequestering carbon according to plan. There is risk that less emission

¹⁷ Allowing purchase of offsets from anywhere in the world would reduce the cost of achieving a given level of emission reduction, but would increase risks and increase the complexity of enforcement.

mitigation will be achieved than is planned, even if the landowner properly performs all needed land management work. Unless payments for emission mitigation are substantial, on a per acre basis, landowners may not be willing to accept much responsibility for delivering a given number of tons of emission mitigation.

Several programs exist that could be building blocks for constructing an emission mitigation purchase program. Federal conservation incentive programs have substantial experience contracting with farmers to get implementation of conservation practices. Methods for tracking sequestration for California's voluntary greenhouse gas emission registry could be adapted for quantifying sequestration. Forest and soil carbon models developed to support U.S. greenhouse gas emission inventories can be used to estimate amounts of emission mitigation expected to be achieved by implementing a particular practice across a particular area. Consultants who currently conduct forest inventories and value forest properties are well positioned to add forest carbon stock measurement and projection to the array of services that they sell. The Farm and Ranchlands Protection Program and other easement programs can hold conservation easements and track compliance with easement provisions.

Ownership of offsets is an issue in auction programs. In general, only direct emission benefits should be sellable. Direct emission benefits are benefits that occur on or within lands or facilities owned or controlled by the entity selling the benefit. For example, the sequestration achieved by growing a tree on someone's property is direct to the owner of the property. In contrast, if someone builds a windmill and generates electricity with the windmill and sells that electricity into the grid and the electricity from the windmill causes the operator of a gas fired generation plant to back down the gas plant, then the emission reduction is direct to the gas plant and indirect to the windmill owner, and the windmill owner would not own or be able to sell the gas plant's emission reduction. A policy that gives emission reduction credits to the windmill operator risks double counting if benefits, when the gas plant operator claims the same reduction a second time.

Practices that claim to mitigate emissions by reducing production of goods, but without reducing demand for those goods, generally displace emissions to other locations and provide little net emission reduction. An auction program should categorically exclude types of projects that have a significant risk of displacement of emissions negating benefits achieved within the project boundary.

Finally, financing a State offset purchase program will be challenging in the current budget environment. However, there may be options to redirect existing agricultural and forestry funding sources to encourage sequestration activities.

A Cap and Trade Program for Carbon Sequestration

Cap and trade programs for pollution are recognized as efficient ways to motivate large emitters of pollution to find and achieve low cost pollution reductions. The most commonly used example of a successful cap and trade program for pollution is the U.S. national sulfur dioxide allowance trading program. Although people typically think of

industrial emitters when they think of cap and trade programs for air pollution, it is possible to construct a system that would cap emissions from lands at current levels, or even require regulated landowners to achieve some net sequestration. Including the agriculture and forestry sectors in a trading system creates opportunity for achieving additional emissions reductions to meet a state target. This section discusses how a system could be constructed that would require large landowners to maintain or increase carbon stocks on their lands, and allow landowners to sell offsets if they store more than what they are required to hold.

The regulator must set standards defining how well emitters or verifiers must count emissions. Because there are many forms of carbon in lands, and efficient methods for counting terrestrial carbon stocks vary depending on the vegetation, soil, climate, and management, it is a non-trivial problem to define accounting standards. The regulator should resist pressure to establish a single set of accounting methods to be applied to all lands, because on many sites the practices will be at best too expensive, and at worst give inaccurate results. Instead, the regulator should define quality standards for accounting and hold emitters and verifiers to these standards. Requiring third party verification of accounts can reduce the risk that accounts fail to meet standards.

The total carbon stock land owners are required to hold may be set at the current amount, some expected business-as-usual trend, or amounts that rise over time. Setting the amount at the current stock requires landowners to offset any reductions in their carbon stocks. Setting the cumulative baseline according to a projected business-as-usual trend would not provide benefit beyond the business-as-usual outcome, and would not be worth the cost of measurements and monitoring. Setting a cap at the projected business-as-usual trend would reduce the risk of sequestration being less than projected. Setting amounts of required sequestration so that the aggregate amount increases over time faster than the business-as-usual scenario would require landowners to sequester carbon faster than they are expected to without emission mitigation requirements, offsetting emissions that occur elsewhere in the state's economy.

In other air pollution emission limitation systems, accounting periods are for a year or less (when peak levels of pollutants are the primary concern accounting periods can be one hour long or less). For forests and soils, because of the costs of quantifying carbon stocks and the modest rate at which these stocks generally grow relative to their starting amounts, it is efficient to use longer accounting periods, such as five year periods.

The overall cost of a given amount of emission mitigation would be lower if lands were included as a part of an emission cap that covers a broad portion of the economy, rather than having a separate cap that is unique to lands and separate from the rest of the economy. As a part of a broad emission reduction system, landowners could sell or buy allowances or offsets, as suits their particular circumstances.

A major advantage of a broad cap is that the regulator sets the baseline and there is much less effort and contention that arises when projects outside of a capped system attempt to set baselines. Two general approaches to setting baselines come to mind. First is setting

a cap tailored to the entity's unique circumstances. For facilities, the baseline is often a fixed percentage of emissions in some earlier period, such as an annual allowable emission of 94% of the entity's average annual emissions in years 2000 through 2004. Analogously, for lands, an entity might be required to hold at least the average carbon stock held in the period 2000 through 2004, or acquire allowances to cover any reduction in stocks below this level. A difficulty in starting this system is that all regulated landowners need to establish measurements of their baseline carbon stocks that were present during a period in the past (for which necessary data may not exist) and everyone will need this work done at the same time, even though an extensive system of verifiers does not exist.

The other obvious approach to setting baselines is to set average baseline stocks for different land classes. The State's existing map of "Wildlife Habitat Relationship" land cover types could serve as an initial stratification system for assigning baseline carbon stocks to land. For forest cover types, it may be possible to stratify by productivity classes within the land cover types.

Regulators may wish to start with a program that includes carbon stocks in vegetation and woody debris, and does not include soil carbon. If a vegetation carbon program is sufficiently successful, regulators could consider how soil carbon stocks could be quantified under a regulatory system, and consider the trade off between precisely detecting small changes in carbon stocks in surface soils versus broadly capturing soil carbon stock changes including those that occur deep in the soil profile.

If a vegetation carbon emission limitation system is established, some landowners will want the system to give them ownership of offsets for amounts of carbon stored in wood products they remove from their lands and sell to others. If land owners are given credit for carbon stocks owned by others, there is a significant risk of double counting of tons unless the entities that actually own the carbon and physically possess it are prohibited from counting it as sequestration. A hybrid system could be established where landowners can claim credit for amounts of carbon assumed to be persisting in wood products in use, but not count any carbon that might be stored in wood wastes. Landfill owners could be allowed to claim credit for amounts of carbon stored by wood placed into landfills. This would give waste management firms an incentive to continue storing carbon in wood waste while allowing forest landowners to generate enough credits to encourage their political support of a cap on forest carbon stock reductions.

A fundamental question in designing a cap and trade system is who to include. A system could be established where every landowner holding more than a specified number of acres within the state must participate. The criteria for participation would be very clear and enforceable. And the total number of landowners could be very tractable. Table 6 shows how many private landowners would be included in the system, and what percentage of private forest lands would be included at various land holding size thresholds. Requiring all landowners holding 50 acres or more to participate would encompass 80% of the private forest lands in the state and involve 47,000 owners. This number of owners is a fraction of the number of land parcels tracked by each of the

county assessors within the state, with the possible exception of the most rural counties with large amounts of federal land. Encompassing 45% of private forest lands would require controls on only 2,419 landowners.

Minimum Ownership Included (acres)	Number of Owners Included	Percentage of Owners Included	Number of Acres Included	Percentage of Acres Included
10	143,078	41.4	13,288,968	91.8
50	46,656	13.5	11,624,228	80.3
100	21,773	6.3	9,901,584	68.4
500	2,419	0.7	6,528,676	45.1
1000	1,037	0.3	5,616,688	38.8

Table 6. Number of private forest land owners and acres of private forest land encompassed by ownerships of state sizes and larger within the State of California. These numbers were calculated using national average distributions of ownership sizes given in Birch (1996) for 1994. The average ownership size in California was slightly greater than the national average, so these numbers would slightly overestimate the number of owners encompassed by a given threshold in 1994. However, the size of forest ownerships is decreasing over time so a given minimum ownership size would now encompass fewer acres and would probably encompass a somewhat greater number of landowners.

A system that requires participation of all owners having more than a minimum size ownership reduces the difficulty of determining who must participate. There would be some difficulty in identifying owners who hold enough land that they must participate, but hold less than the threshold amount in any single county. There could be an issue of preventing gaming, for example, landowners splitting up land parcels among corporations so that each corporation has less than the amount of land that triggers participation. It would be necessary to define participating land parcels based on corporate control, and perhaps as of a historic date.

Costs of measuring and monitoring forest and soil carbon stocks are somewhat insensitive to the area of land being measured. Doubling the size of the area being measured might only increase the cost of measurement by a few percent. Conversely, halving the size of the area being measured does little to reduce measurement costs. As a result, as the size of the area being measured goes down, the cost per acre of measurement goes up. As techniques are developed, measurement and monitoring costs are going down, but in the authors' experience it can still cost \$20,000 to do a carbon stock measurement. Measurements would need to be done every five or ten years. To keep the cost to the landowner to a couple dollars per acre per year, it might be necessary to start with only landowners holding substantial amounts of land, such as 1,000 acres or more.

If public land can be included in the system, the area of forest land encompassed could be increased dramatically, with a negligible increase in the number of owners. Forest Service analysis indicates that there are more than 23 million acres of public forest land in California. If this land could be incorporated into a carbon sequestration system, the

total area encompassed by the program would be tripled relative to only including private ownerships greater than 50 acres.

As a model for a system that limits CO₂ emissions from land, California already has at least one air pollution emission trading system, the California South Coast RECLAIM trading credit program for NO_x emissions. This system could provide a model for a carbon sequestration trading system, and possibly could provide a registry and trading platform.

Permanent versus Temporary Tons

If a ton of carbon stored in biomass is released to the atmosphere, that emission should be counted. As a result, in cases where the landowner only commits to maintaining sequestration for a specified period of time, and a property subsequently leaves the accounting system, the sequestration accomplished on that property should be cancelled by counting it as an emission. For example, under an auction system the state could contract with landowners such that the landowner commits to carrying out specified land management practices for the 10 or 15 year life of the contract, like federal Conservation Reserve Program contracts. If, at the end of a contract period, the landowner does not renew the contract, then the carbon sequestered on the lands should be counted as an emission.

Different lands may be enrolled, to replace the lost sequestration. However, most terrestrial sequestration activities take several years to store carbon. As a result, if a property leaves the sequestration program and is replaced by a new parcel of the same size and productivity where sequestration practices are being newly initiated, the average amount of carbon stored will be less than what would be stored if the first parcel remained in the system.

The turnover of lands in a program with fixed-term contracts will increase the price per ton to an amount greater than if there were no turnover of lands.

Owning Tons versus Owning Land

If an entity purchases rights to sequestration without purchasing the land where the sequestration is accomplished, the potential for conflict arises. At the time a landowner enters into a voluntary agreement to sequester carbon, that landowner is choosing sequestration. However, over time, the landowner's circumstances may change and the landowner may wish to use the land in a way that would reverse the sequestration. For example, the landowner may commit to growing trees, and when those trees grow large and valuable, that landowner may wish to log the trees and sell the timber. Also, land ownership changes over time. A new owner who acquires land with an obligation to maintain sequestration on that land may not wish to continue the land management practices necessary to maintain the sequestration. The longer the time the obligation to maintain sequestration persists, the greater the chance that a landowner will not wish to

continue the obligation. If permanent sequestration in vegetation is desired, it may be advantageous to acquire the land on which sequestration is accomplished.

Who Owns Offsets

Sequestration that occurs in soil or forest vegetation is typically owned by the landowner. As a result, there is little risk to an offset buyer to purchase offsets from a landowner, as long as the sequestration did not result from activities paid for by someone else who might claim resulting emission benefits.¹⁸ When sequestration or emission reductions occur within lands or facilities owned or directly controlled by an entity, the mitigation is referred to as direct to that entity.

Forest management activities may lead to emission mitigation that is indirect to the forest landowner. Specifically, if forest landowners grow biomass that is used by a power plant operator to displace fossil fuel in electricity generation, the emission reduction is direct to the power plant operator and indirect to the forest landowner.

Policies for promoting emission mitigation are generally more effective if they directly affect entities the policy intends to encourage to mitigate emissions. In the case of power generated from biomass, then means that the policy is more likely to be efficient if payments are made to power generators who use biomass than if payments are made to landowners to get them to offer biomass to anyone who may wish to buy it.

Education programs are an exception to the rule about dealing directly with entities expected to directly mitigate emissions. For example, a carpool coordination program could be funded with emission mitigation money, for the purpose of encouraging reductions in driving. If reductions occur, they would be direct to drivers. For programs where emission mitigation is directly achieved by many emitters, with each making a small reduction, it may be efficient to pay for mitigation by making payments to a coordinating entity. With respect to education programs, a caution is in order. There is no way to tell if an education program works to mitigate emissions unless a well-designed monitoring system is in place at the beginning of the program, and the monitoring system is used to measure the effects of the education program on greenhouse gas emissions.

Timing of Expenditure versus Achieving Benefits

Many terrestrial carbon sequestration activities require investment to make a change in land conditions or land management practices, but do not yield net emission mitigation until years or decades later. Afforestation provides an example. For afforestation to

¹⁸ If the activity that causes sequestration is required by regulation, the resulting sequestration generally would not count as an offset in a voluntary system. In a mandatory system where the baseline is defined by the regulator, sequestration that results from required activities may or may not count as an offset, depending on what accounting policies are set by the regulator.

occur, lands must be identified, landowner commitment to afforestation obtained (or the lands must be acquired outright), plans developed, site preparation performed, seedlings planted, and the young stand tended until it is well established. Yet the project provides little sequestration, if any, for years because small tree seedlings store little carbon.

When comparing alternative projects using levelized costs, the levelizing accounts for differences in the timing of costs and benefits. However, if an entity needs emission reductions soon, a terrestrial sequestration project may not deliver the tons in time, even if both the undiscounted and levelized costs of sequestration by the project are low. Even when the levelized cost of offsets is low, the public may or may not support spending limited resources allocated to mitigating emissions on activities that will yield little or no mitigation for a decade or more. In general, when considering sequestration projects, one should consider the schedule of spending and the timing of expected emission mitigation, in addition to the levelized cost per ton of mitigation.

Policy Goals may Conflict

A particular land management activity may support one policy goal while conflicting with another. An example of this divergence is landfilling of yard waste. For many years, most municipalities have encouraged a variety of ways of handling of yard waste to avoid landfilling that waste. Most often the municipalities want to conserve limited landfill space for other wastes that are not amenable to disposal other than by landfilling. Another reason to avoid landfilling yard waste is the desirability of reusing the nutrients incorporated in the waste, which can be accomplished by composting the material to create a soil amendment.

From a greenhouse gas perspective, landfilling yard waste may be preferable to mulching or composting that waste, because more of the carbon in the waste remains sequestered with landfilling.

However, just because a particular land use would provide a greenhouse benefit, it does not mean that public decision makers should choose that land use. Other benefits from alternative uses may be greater. For example, restoring wetlands may increase net greenhouse warming because the restored wetland may emit methane. However, wetlands also improve water quality, provide habitat, support fish reproduction, and may provide buffers against flooding. Considering the trade-offs across multiple policy goals, it may be better to choose an option that does not provide greenhouse emission mitigation.

Fortunately, many activities that mitigate greenhouse gas emissions also provide other environmental benefits. For example, restoring riparian forests provides greenhouse benefits by sequestering carbon, can improve water quality, and usually improves fish habitat. Policy makers may wish to seek greenhouse emission mitigation activities that serve other pre-existing policy goals, to leverage investments already being made to serve those pre-existing goals.

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